This is to certify that the attached English language document, identified as Wavelength converter and wavelength division multiplexing transmission method using same, is a true and accurate translation of the original Japanese Patent application JP11-374813 to the best of my knowledge and belief.

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Katsuhiko Miki

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[To] Director of Japanese Patent Office
[Inventor]
[Address or residence] c/o the Furukawa Electric company 6-1, 2 choume, marunouchi, chiyoda-ku, tokyo
[Name] Osamu Aso
[Address or residence] c/o the Furukawa Electric company 6-1, 2 choume, marunouchi, chiyoda-ku, tokyo
[Name] Shu Namiki
[Address or residence] c/o the Furukawa Electric company 6-1, 2 choume, marunouchi, chiyoda-ku, tokyo
[Name] Kouki Sato
[Address or residence] c/o the Furukawa Electric company 6-1, 2 choume, marunouchi, chiyoda-ku, tokyo
[Name] Hijiri Nimura
[Applicant]
[ID Number] 000005290
[Name] The Furukawa Electric Company
[Attorney]
[ID Number] 100076369]
[Patent Attorney]
[Name] Kobayashi, Masaharu
[Fee]
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[Title of the invention]

Wavelength converter and wavelength division multiplexing transmission method using same

[Claims]

[Claim 1] A wavelength converter using four-wave mixing (FWM) in optical fibers or semiconductor optical amplifier (SOA), wherein one or more optical lightwaves are filtered our from wavelength-division multiplexed (WDM) lightwaves inputted to the wavelength converter by and optical component that has the filtering functionality in frequency domain, and solely the filtered out lightwaves are wavelength converted.

[Claim 2] A wavelength converter according to claim 1, wherein solely the filtered out lightwaves from the WDM source inputted to the wavelength converter is wavelength converted by FWM, and the wavelength converted lightwaves are combined with the lightwaves neither to be filtered out nor to be wavelength converted, and provide an alternative channel configuration of the WDM lightwaves to the WDM lightwaves inputted to the wavelength converter in wavelength domain.

[Claim 3] A wavelength converter according to claim 1, wherein solely the filtered out lightwaves from the WDM source inputted to the wavelength converter is wavelength converted by FWM, and the wavelength converted lightwaves are combined with the one or more lightwaves any of those wavelength are not coincided with all the wavelength of the converted lightwaves, and provide an alternative channel configuration of the WDM lightwaves to the WDM lightwaves inputted to the wavelength converter in wavelength domain.

[Claim 4] A wavelength converter according to any one of claims 1 to 3, wherein one or more optical components each has the filtering function to filter out one or more lightwaves in each N channels frequency spacing (N is a positive integer) from the WDM lightwaves inputted to the optical component, is used as the optical component, and the lightwaves filtered out by each components are wavelength converted independently or simultaneously by use of the FWM.

[Clam 5] A wavelength converter according to any one of claims 1 to 3, wherein optical components having the filtering functionality are used to filter out one or more clusters of the WDM lightwaves in the wavelength

domain (sub-bands) that are constituents of the WDM lightwaves inputted to the wavelength converter, and one or more sub-bands are wavelength onverted simultaneously or independently by use of the FWM.

[Claim 6] A wavelength converter wherein:

an optical demultiplexing device is connected after the wavelength converter according to claims 4 or 5 to demultiplex the WDM lightwaves with high extinction ratio, thereby providing an enhanced optical demultiplexing module in comparison of the optical demultiplexing device.

[Claim 7] A wavelength converter using four-wave mixing (FWM) in an optical fiber or a semiconductor optical amplifier, wherein:

input WDM lightwaves are divided into two or more lightwaves by an optical divider, and one or two or more lightwaves outputted from the output port of the divider are wavelength converted.

[Claim 8] A wavelength converter according to claim 9, wherein some outputted lightwaves from the output port of the optical divider are wavelength converted by FWM, and the wavelength converted lightwaves and the outputted lightwaves from the remained output port are combined with by an optical combiners to obtain WDM lightwaves whose configuration in wavelength domain, is different from the configuration of the input WDM lightwaves.

[Claim 9] A wavelength converter according to claim 9, wherein some outputted lightwaves from the output port of the optical divider are wavelength converted by FWM, and the wavelength converted lightwaves and the WDM lightwaves all of whose wavelength are different from any of the wavelength converted light, are combined with by an optical combiners to obtain WDM lightwaves whose configuration in wavelength domain, is different from the configuration of the input EDM lightwaves.

[Claim 10] A wavelength-division multiplexing transmission method wherein:

output WDM signals from the wavelength converter whose frequency interval is broaden in comparison of the WDM signals input to the wavelength converter is obtained by using the wavelength converter according to claim 4 or 5, and the output WDM signals is transferred from the transmission line less influenced by the inter-channel crosstalk to the transmission line strongly influenced by the crosstalk.

[Claim 11] A wavelength-division multiplexing transmission method

wherein:
output WDM signals from the wavelength converter whose frequency interval is reduced in comparison of the WDM signals input to the wavelength converter is obtained by using the wavelength converter according to claim 6 or 7, and the output WDM signals is transferred from the transmission line strongly influenced by the inter-channel crosstalk to the transmission line less influenced by the crosstalk.
[Claim 12] A wavelength-division multiplexing transmission method according to claim 13, wherein:
the wavelength bands with no WDM signals that are realized as result of wavelength converter described in claim 13, are used to add external WDM signals any of whose wavelength are not coincided with all of the wavelength of the wavelength converted signals, by combing the two WDM signals, and the combined WDM signals are transmitted.
[DETAILED DESCRIPTION OF THE INVENTION]
[0001]
[FIELD OF THE INVENTION]
The present invention relates to a wavelength converter applicable to a network based on wavelength-division multiplexing (WDM) transmission in optical communication systems and wavelength-division multiplexing transmission method using the same.
[0002]
[PRIOR ART]
Because of the development of the WDM transmission technologies and optical amplifiers, WDM networks have been studied extensively by many researchers. Interconnection of the WDM systems that are independently designed and constructed is required cost effectively. For the purpose of satisfying the requirements, several types of the wavelength conversion techniques have been studied. Fiber-optic four wave mixing (FWM) based parametric wavelength conversion is one of the very promised techniques for applying to the broadband WDM networks because of its bit-rate transparency (response time ~100fs), and its ability to process the multi-channels optical signals simultaneously. It is known that the FWM based parametric wavelength conversion is also realized in semiconductor optical amplifiers (SOA's).
[0003]

[PROBLEM TO BE SOLVED]

Since the multi-channels simultaneous wavelength conversion is realized by optical parametric processes in nonlinear media, it seems that so far most of the researchers have devoted to broaden the bandwidth of the wavelength conversion in wavelength domain to follow the increment of the extraordinary number of channels. However, from the practical point of view, not only the broadband multi-channels simultaneous wavelength conversion, but also different applications of the parametric wavelength conversion to the WDM networks should be conceived to enhance the flexibility of the signal processing.

[0010]

[MEANS TO SOLVE THE PROBLEM]

An object of the present invention is to provide a wavelength converter in which only some lightwaves that are the constituent of all the WDM lightwaves, are filtered out in frequency domain, then only the filtered out lightwaves are wavelength converted parametrically by use of FWM in optical fiber or in SOA, and to provide WDM transmission methods in which the above types of the parametric wavelength converter is applied to enhance the flexibility of the wavelength routing and signal processing in WDM networks.

[0011] Because of its frequency dependence of the transmittance and/or reflectivity of the filtering components, such as dielectric thin films and gratings, some lightwaves that are constituent of the inputted WDM lightwaves (hereinafter referred to as the original WDM lighwaves), can be filtered out then transmitted (or reflected) lightwaves are outputted from the one output port. The remained lightwaves not to be transmitted (or not to be reflected) are reflected (or transmitted) and outputted from the other output port. Solely the transmitted (or reflected) lightwaves outputted from the components can be simultaneously wavelength converted by the parametric wavelength converter concatenated with after the filtering components. The present invention provides a wavelength converter in which the lightwaves, that are required to be wavelength converted, are filtered out by one or more filtering components, then the filtered out lightwaves are simultaneously wavelength converted by a FWM based parametiric wavelength converter. The present invention provides further a wavelength converter in which, WDM lightwaves are divided by an optical

divider, the one divided WDM lightwaves are outputted from the one output port of the divider directly. The other lightwaves are outputted from each the remained output port and lightwaves outputted from each output port are wavelength converted independently. The wavelength converted WDM lightwaves after outputted from the output ports, and the WDM lightwaves not to be wavelength converted after outputted from the divider, are combined with together without duplicating in frequency domain. The present invention also provides wavelength-division multiplexing transmission method using the FWM based parametric wavelength converter concatenated with after the optical filters or the optical dividers.

[0012] According to a first aspect of the present invention, there is provided a wavelength converter using four-wave mixing (FWM) in optical fibers or semiconductor optical amplifier (SOA), wherein one or more optical lightwaves are filtered our from wavelength-division multiplexed (WDM) lightwaves inputted to the wavelength converter by and optical component that has the filtering functionality in frequency domain, and solely the filtered out lightwaves are wavelength converted.

[0013] According to a second aspect of the present invention, there is provided a wavelength converter, wherein solely the filtered out lightwaves from the WDM source inputted to the wavelength converter is wavelength converted by FWM, and the wavelength converted lightwaves are combined with the lightwaves neither to be filtered out nor to be wavelength converted, and provide an alternative channel configuration of the WDM lightwaves to the WDM lightwaves inputted to the wavelength converter in wavelength domain.

[0014] According to a third aspect of the present invention, there is provided a wavelength converter, wherein solely the filtered out lightwaves from the WDM source inputted to the wavelength converter is wavelength converted by FWM, and the wavelength converted lightwaves are combined with the one or more lightwaves any of those wavelength are not coincided with all the wavelength of the converted lightwaves, and provide an alternative channel configuration of the WDM lightwaves to the WDM lightwaves inputted to the wavelength converter in wavelength domain.

[0015] According to a fourth aspect of the present invention, there is provided a wavelength converter, wherein one or more optical components each has the filtering function to filter out one or more lightwaves in each

N channels frequency spacing (N is a positive integer) from the WDM lightwaves inputted to the optical component, is used as the optical component, and the lightwaves filtered out by each components are wavelength converted independently or simultaneously by use of the FWM.

[0016] According to a fifth aspect of the present invention, there is provided a wavelength converter according to any one of claims 1 to 3, wherein optical components having the filtering functionality are used to filter out one or more clusters of the WDM lightwaves in the wavelength domain (sub-bands) that are constituents of the WDM lightwaves inputted to the wavelength converter, and one or more sub-bands are wavelength onverted simultaneously or independently by use of the FWM.

[0017] According to a sixth aspect of the present invention, there is provided a wavelength converter wherein:

an optical demultiplexing device is connected after the wavelength converter according to claims 4 or 5 to demultiplex the WDM lightwaves with high extinction ratio, thereby providing an enhanced optical demultiplexing module in comparison of the optical demultiplexing device.

[0018] According to a seventh aspect of the present invention, there is provided a wavelength converter using four-wave mixing (FWM) in an optical fiber or a semiconductor optical amplifier, wherein:

input WDM lightwaves are divided into two or more lightwaves by an optical divider, and one or two or more lightwaves outputted from the output port of the divider are wavelength converted.

[0019] According to an eighth aspect of the present invention, there is provided a wavelength converter, wherein some outputted lightwaves from the output port of the optical divider are wavelength converted by FWM, and the wavelength converted lightwaves and the outputted lightwaves from the remained output port are combined with by an optical combiners to obtain WDM lightwaves whose configuration in wavelength domain, is different from the configuration of the input WDM lightwaves.

[0020] According to a ninth aspect of the present invention, there is provided a wavelength converter, wherein some outputted lightwaves from the output port of the optical divider are wavelength converted by FWM, and the wavelength converted lightwaves and the WDM lightwaves all of whose wavelength are different from any of the wavelength converted light,

are combined with by an optical combiners to obtain WDM lightwaves whose configuration in wavelength domain, is different from the configuration of the input EDM lightwaves.

[0021] According to a tenth aspect of the present invention, there is provided a wavelength-division multiplexing transmission method wherein: output WDM signals from the wavelength converter whose frequency interval is broaden in comparison of the WDM signals input to the wavelength converter is obtained by using the wavelength converter according to claim 4 or 5, and the output WDM signals is transferred from the transmission line less influenced by the inter-channel crosstalk to the transmission line strongly influenced by the crosstalk.

[0022] According to an eleventh aspect of the present invention, there is provided a wavelength-division multiplexing transmission method wherein: output WDM signals from the wavelength converter whose frequency interval is reduced in comparison of the WDM signals input to the wavelength converter is obtained by using the wavelength converter, and the output WDM signals is transferred from the transmission line strongly influenced by the inter-channel crosstalk to the transmission line less influenced by the crosstalk.

[0023] According to a twelfth aspect of the present invention, there is provided a wavelength-division multiplexing transmission method, wherein:

the wavelength bands with no WDM signals that are realized as result of wavelength converter described in claim 13, are used to add external WDM signals any of whose wavelength are not coincided with all of the wavelength of the wavelength converted signals, by combing the two WDM signals, and the combined WDM signals are transmitted.

[0030]

[EMBODIMENTS OF THE INVENTION]

(First embodiment of wavelength converter)

A wavelength converter according to a first embodiment of the present invention will now be explained with reference to Fig. 1. The wavelength converter corresponds to the aforementioned first aspect of the present invention. In Fig. 1, a broadband multi-channel simultaneous wavelength conversion portion 10 is composed of a pump source 2 that generates pump light for the use of the FWM generation, an optical

combiner 3 for combining the pump light with lightwaves required to be wavelength converted filtered out from original WDM lightwaves by an optical filter 1, a nonlinear element (optical fiber for the use of wavelength conversion) 4 to generate wavelength converted lightwaves as a resultant of the FWM, and an optical filter 5 for removing the pump and the lightwaves required to be wavelength converted of the output lightwaves from the optical fiber 4. And an optical component 1(for example, optical filter 1) capable of filtering out the lightwaves required to be wavelength converted from the original WDM lightwaves is also the constituent of the broadband multi-channels simultaneous wavelength conversion portion. The optical fiber 4 as a nonlinear element shown in Fig. 4 can be replaced by a semiconductor optical amplifier (SOA). The concept of the optical filter 5 is interpreted more wider sense, the filter includes e.g., nonlinear-optical loop mirror. The above definition is generally used to the other drawings appeared in the following embodiments throughout the documents.

[0031] In this wavelength converter, one or more optical lightwaves required to be wavelength converted are predetermined (hereafter referred as "lightwaves required to be wavelength converted") and are filtered out from the original WDM lightwaves by use of the optical filter 1, and the remained lightwaves that are not required to be wavelength converted" is outputted from the other port of the optical filter 1. The lightwaves required to be wavelength converted are combined with pump light emitted from the pumping source 2 by the optical combiner 3. The combined lightwaves are launched into the optical fiber 4 to generate four-wave mixing. Output lightwaves from the fiber 4 is then launched into the optical filter 5 to remove both the pump light and the lightwaves required to be wavelength converted. Consequently, solely the wavelength converted lightwaves are outputted at the output end of the filter 5. By changing wavelength dependence of the transmittance characteristics, various types of the wavelength conversion can be realized.

[0040](Second Embodiment of Wavelength Converter)

A wavelength converter according to a second embodiment of the present invention will now be explained with reference to FIGS. 2 and 3. The wavelength converter corresponds to the aforementioned second aspect of the present invention. FIG. 3 is a view for explaining wavelength conversion procedures of lightwaves in the second wavelength converter.

In FIG. 2, a broadband multi-channel simultaneously wavelength conversion portion 10 is composed of a pump source 2, an optical combiner 3, optical fiber 4 and an optical filter 5. An optical filter 1 and an optical combiner 6 are both constituent of the portion 10. The optical filter 1 is applied to filter out the lightwaves required to be wavelength converted from the original WDM lightwaves with channel intervals N=1 (filtering out the channels alternately) in wavelength domain. The optical filter 1 is a Fabry-Perot etalon filter in this embodiment and transmittance of the filter 1 has its peaks periodically in 2 channels spacing in wavelength domain. The lightwaves required to be wavelength converted are combined with pump light emitted from the pump source 2 by an optical combiner 3.

[0041] The combined lightwaves are launched into the optical fiber 4 and wavelength converted lightwaves are generated simultaneously by virtue of the FWM in the fiber 4. Solely the wavelength converted lightwaves are filtered out by the optical filter 5. The wavelength converted lightwaves output from the portion 10 are combined with the lightwaves required not to be wavelength converted that are outputted from the optical filter 1. Consequently, configuration of the wavelength of WDM lightwaves outputted from the wavelength converter is different from the original WDM lightwaves. The wavelength interval of the WDM lightwaves outputted from the wavelength converter is broader than that of the original WDM lightwaves by twice.

[0050] (Third Embodiment of Wavelength Converter)

A wavelength converter according to a third embodiment of the present invention will now be explained with reference to FIGS. 4 and 5. Schematic of the apparatus of the wavelength converter is shown in FIG. 4. FIG. 5 is a view for explaining wavelength conversion procedures of lightwaves in the third wavelength converter. In FIG. 4, a broadband multi-channel simultaneously wavelength conversion portion 10 is composed by a pump source 2, an optical combiner 3, optical fiber 4 and an optical filter 5. An optical filter 1 and an optical combiner 7 are both constituent of the portion 10. As shown in FIG. 5, the lightwaves required to be wavelength converted are filtered out on alternate channels from the WDM lightwaves 1, and the lightwaves required to be wavelength-converted are combined with pump light from the pump source 2 by an optical combiner 3. The combined lightwaves are launched into the

optical fiber 4 and wavelength converted lightwaves are generated by four-wave mixing (FWM) in the fiber. Output lightwaves from the optical fiber 4 is launched into the optical filter 5 and solely the wavelength converted lightwaves are outputted from the filter 5. The end of the other output port of the optical filter 1 is anti-reflection coated not to output the lightwaves required not to be wavelength converted. Thus the wavelength converted lightwaves and externally launched WDM lightwaves 2 are combined with by the optical combiner 7 to reconfigure alternative WDM lightwaves in wavelength domain. Concerning the wavelength conversion, it should be remarked that any wavelength of the wavelength converted lightwaves must not be coincided with all the wavelength of the launched WDM lightwaves.

[0051] The wavelength of the pump light .lambda..sub.p generated from the pump source 2 shown in FIG. 4 is determined by the frequency phase-matching condition (or equivalently energy conservation law) among the a constituent of the WDM lightwaves 2 whose wavelength is .lambda..sub.2 and wavelength of the corresponding wavelength converted lightwave .lambda..sub.2 that is predetermined from the knowledge of the system design. The result is as follows,

[0052]

[Equation 1]

$$\lambda_p = \frac{1}{2}\left(\frac{\lambda_2 \lambda_2'}{\lambda_2 + \lambda_2'}\right)$$

From the requirement of the propagation constant phase-matching condition (or equivalently momentum conservation law), zero-dispersion wavelength of the optical fiber 4 must be in the vicinity of the .lambda..sub.p represented in equation (1).

[0060]

(Fourth Embodiment of Wavelength Converter)

A wavelength converter according to a fourth embodiment of the present invention will now be explained with reference to FIGs. 6 and 7. The wavelength converter is the fourth aspect of the present invention. FIG. 7 is a view explaining a light with wavelength converted by the wavelength converter as shown in FIG. 6. The wavelength converter uses

filters in two stages in which WDN lightwaves are filtered out in every two channels (with 2 channels frequency spacing) to separate the lightwaves to be wavelength converted from the lightwaves not to be wavelength converted.

[0061]

In the wavelength converter as shown in FIG. 6, the first lightwaves to be wavelength converted are filtered out by the first optical filter 1 from WDM lightwaves with 2 channels frequency spacing as shown in FIG. 7. The filtered lightwaves are combined with a pump light from the first pump source 2 by the first optical coupler 3, then the combined lightwaves are input into the first fiber for wavelength conversion to obtain the first wavelength converted lightwaves, and passed through the filter 5.

[0062]

Second lightwaves to be wavelength converted is filtered out with the channel frequency spacing of N-1 by the second filter from the lightwaves not filtered out by the first optical filter, then the filtered lightwaves are combined with a pump light from the second pump source 13 by the second fiber for wavelength conversion, then the combined lightwaves are input into the second fiber 15 for wavelength conversion to obtain the second wavelength converted light, and then passed through the filter 5. Thus transmitted lightwaves are combined with the lightwaves not filtered out from the second filter 11 to generate a new WDM lightwaves. The WDM lightwaves are combined with the first wavelength converted lightwaves by the third optical coupler to be output. The output lightwaves are new WDM lightwaves in which the frequency spacing thereof is at least three times (N+1) of that of the original WDM lightwaves as shown in FIG. 7.

[0063]

The wavelength converter shown in FIG. 6 extends the procedure with channel spacing N=1 to N=2. In the same manner, the procedure can be extended to arbitral N (N is an integer). In case that the wavelength is converted by the wavelength converter as shown in FIG. 6, the input lightwaves are N-channel WDM lightwaves, the wavelength are $\lambda 1$, $\lambda 2$, ····, λN, and the WDM lightwaves are positioned with the same frequency spacing. When the WDM lightwaves are filtered out in every k channels, an etalon filter having periodical peak transmissivity with the

spacing is applied as the first and second optical filters.

[0064]

Wavelengths of the wavelength converted lightwaves obtained by the first optical filter (etalon filter) are λ1', λ2', ·······, λm' from the short wavelength side. Similarly, wavelengths of the wavelength converted lightwaves obtained by the second optical filter (etalon filter) are λ1", λ2", ·······, λm" from the short wavelength side. Wavelength of the lightwaves not filtered out by the first or second filter are λ10, λ20, ·······, λm0. The pump light wavelength of the first pump source 2 is set as the following equation (2)

[0065]

[Equation 2]

$$\lambda_{p1} = \frac{1}{2}\left(\frac{\lambda_{m0}\lambda_{mc}'}{\lambda_{m0} + \lambda_{mc}'}\right)$$

Where, λ1', λ2', ·······, λm' are to be converted to λ1c', λ2c', ·······, λmc'

[0066]

Concerning the pump light wavelength of the second pump source 13, when λ1", λ2", ·······, λm" are considered to be converted to λ1c", λ2c", ·······, λmc", λmc is selected to satisfy λ1c'<λmc", thus the following equation (3) is determined:

[Equation 3]

$$\lambda_{p2} = \frac{1}{2}\left(\frac{\lambda_{m}''\lambda_{mc}''}{\lambda_{m}'' + \lambda_{mc}''}\right)$$

Thus, when the wavelengths of the first and second pump source are selected, it can be arranged that the wavelengths of the original input WDM lightwaves are not identical to the wavelengths of the obtained WDM lightwaves.

[0070]

(Fifth Embodiment of Wavelength Converter)

A wavelength converter according to a fifth embodiment of

the present invention will be explained. This wavelength converter corresponds to the aforementioned sixth aspect of the present invention. FIG. 8 is a schematic of the wavelength converter, hereafter referred as the "sub-band converter". FIG. 9 is a conceptual schematic to explain the sub-band that is the fundamental concept to explain the present invention. In FIG. 9, 20-channels WDM lightwaves are schematically represented. At present, more than 128 channels of the WDM transmission experiments were demonstrated. Concerning the signal processing of such an extraordinarily number of the channels, the difficulties of the system management increase monotonically as the channel number increases. To resolve the difficulties sub-band management is considered as follows.

[0071]

In Fig. 8, solely sub-band .LAMBDA..sub.3 is filtered out from the input WDM lightwaves by a dielectric multi-layered filter 1 whose transmittance peak covers whole of the wavelength region .LAMBDA..sub.3 in the wavelength domain. The filtered out lightwaves (lightwaves inside the sub-band .LAMBDA..sub.3) are combined with pump light from a pump source 2 by an optical combiner 3. The combined lightwaves are launched into the optical fiber 4 and wavelength converted lightwaves are generated by the FWM in the optical fiber 4.

The information carried by the lightwaves of the sub-band .LAMBDA..sub.3 at the input end of the sub-band converter, are carried by the lightwaves in sub-band .LAMBDA..sub.2 after the sub-band converter by virtue of the sub-band wavelength conversion.

[0073]

$$\lambda_4 < \lambda_p < \lambda_5$$

[0074]

[Equation 4]

$$\lambda_p = \frac{2\lambda_3\lambda_4\lambda_5}{2\lambda_4\lambda_5 + \lambda_3(\lambda_4 - \lambda_3)}$$

[0080]

(Sixth Embodiment of Wavelength Converter)

FIG. 10 shows a wavelength converter according to a sixth embodiment of the present invention. The wavelength converter corresponds to the aforementioned sixth aspect of the present invention. The wavelength converter is arranged by combining the wavelength converter 30 broadening the frequency interval as shown in the second and fourth embodiment of the invention, and the optical demultiplexing module 31. An arrayed waveguide grating (AWG) is one of the examples of such an optical demultiplexer. Typical extinction ratio of AWG is known to be 16 dB at frequency interval 27 GHz. It is known that the extinction ratio can be increased as the frequency interval becomes large in generally. The wavelength converter 30 is applicable to enhance the extinction ratio of the AWG 31 by concatenating with the optical demultiplexer. The frequency interval of the input lightwaves is broadened by the wavelength converter 30. Thus the extinction ratio of the AWG 31 concatenated with after the wavelength converter 30 is enhanced. The optical demultiplexer concatenated with the wavelength converter 30 becomes an optical demultiplexing module with low crosstalk.

[0090]

(Seventh Embodiment of Wavelength Converter)

FIG. 11 shows a wavelength converter according to a seventh embodiment of the present invention. The wavelength converter provides another application of the aforementioned seventh aspect of the present invention. FIG. 12 is a view for explaining wavelength conversion procedures of lightwaves in the wavelength converter shown in FIG. 11. Both the wavelength conversion portion 10 and 20 shown in FIG. 11 can expand the frequency interval of the WDM lightwaves inputted to the each portion as described in the second and fifth embodiments of the present invention. In general, the frequency interval expansion ratio can be realized to be 1/(n+1) for an arbitrary positive integer n by applying the technique shown in the fifth embodiment discussed as follows.

[0091] The first optical filter 1 is a dielectric multi-layered filter. The first lightwaves required to be wavelength converted are filtered out from the optical filter 1. The first lightwaves required to be wavelength converted are combined with the pump light from the pump source 2 by an optical combiner 3. The combined lightwaves are launched into an optical fiber 4. The first wavelength converted lightwaves are generated by FWM in

optical fiber 4. Only the first wavelength converted lightwaves are filtered out from the output lightwaves from the optical fiber 4 by an optical filter 6.

[0092] The lightwaves not to be filtered out by the first dielectric multi-layered filter 1 are launched into the second dielectric multi-layered filter 25. Second lightwaves required to be wavelength converted are filtered out by the filter 25 and combined with pump light from the pump source 21 by an optical combiner 22. The combined lightwaves outputted from the optical combiner 22 are launched into an optical fiber 23 and wavelength converted lightwaves are generated by FWM in the fiber 23. Solely the second wavelength converted lightwaves can be filtered out from the output lightwaves from the fiber 23 by use of the optical filter 24. The second wavelength converted lightwaves are combined with the lightwaves not required to be secondly wavelength converted by the wavelength conversion portion 20, by an optical combiner 26. Then the combined WDM lightwaves outputted from the optical combiner 26 are further combined with the first wavelength converted lightwaves output from the optical filter 6 by an optical combiner 27 in FIG. 20.

A technique to reduce the frequency interval of the WDM lightwaves that were launched into the wavelength converter (hereafter referred as the original lightwaves in this embodiment) is conceived in the following discussions. It will be provided that the resultant frequency interval becomes 1/(n+1), where n is an arbitrary natural number.

[0093] Putting the wavelength of the lightwaves required to be wavelength converted in the first wavelength conversion portion 10 as, λ_{m+1}, λ_{m+2}, . . . , λ_M and the wavelength of the lightwaves required to be wavelength converted in the second wavelength conversion portion 20 as, λ_{S+1}, λ_{S+2}, . . . , λ_m, the integers m, M and S corresponding to the diagram shown in FIG. 11 are m=4, M=6 and S=2 respectively. In this time, the output WDM lightwaves from the wavelength converter whose frequency interval is 1/3can be realized by setting the wavelength of the pump light of the pump source 2 (λ_{p1}) and pump source 21 (λ_{p2}) respectively as follows:

[0094]

[Equation 5]

$$\lambda_{p1} = \frac{6\lambda_1\lambda_2\lambda_M}{3\lambda_1\lambda_2 + \lambda_M(2\lambda_1 + \lambda_2)}$$

[0095]
[Equation 6]

$$\lambda_{p2} = \frac{6\lambda_1\lambda_2\lambda_m}{3\lambda_1\lambda_2 + \lambda_m(\lambda_1 + 2\lambda_2)}$$

The result can be extended to more general case (equivalently arbitrary positive integer n) straightforwardly.

[0100]
(Eighth Embodiment of Wavelength Converter)

FIG. 13 shows a wavelength converter according to a tenth embodiment of the present invention. The wavelength converter corresponds to the aforementioned ninth aspect of the present invention. In FIG. 22, a broadband mulch-channel simultaneous wavelength conversion portion 10 is composed of a pump source 2, an optical combiners 3, an optical fiber 4 for generating the FWM and an optical filter 5. The optical fiber 4 can be replaced to be an SOA.

[0101] FIG. 14 is a view for explaining wavelength conversion procedures of lightwaves in the wavelength converter shown in FIG. 13. Frequency interval of the WDM lightwaves inputted to the wavelength converter is constant. The input WDM optical lightwaves are divided into two by an optical divider. One of the divided WDM lightwaves is the lightwaves required to be wavelength converted and is combined with a pump light from the pump source 2 by an optical combiner 3. The combined lightwaves outputted from the optical combiner 3 are launched into the optical fiber 4 and wavelength converted lightwaves are generated by FWM. Solely the wavelength converted lightwaves are filtered out from the output lightwaves from the optical fiber 4 by the optical filter 5. Consequently, the lightwaves required to be wavelength converted that is outputted from the optical divider are wavelength converted by the broadband multi-channels simultaneous wavelength conversion portion 10. Lightwaves not required to be wavelength converted are outputted from the

other port of the optical divider and are combined with the wavelength converted lightwaves from optical filter 5 by the optical combiner 6 without duplication in wavelength domain. The combined lightwaves are outputted from the wavelength converter. Then we can increase the channel numbers twice in comparison of the original WDM lightwaves.

[0102] N channel WDM optical lightwaves (N is an arbitrary positive integer) are considered as the input WDM lightwaves (referred as the original WDM lightwaves). The wavelength of the N-th lightwave which is a constituent of the original WDM lightwaves is put to be λ N, and λ N is the longest wavelength of the original WDM lightwaves.

Based on the FWM based wavelength conversion, the WDM lightwaves composed of the lightwaves whose wavelength are λ 1, λ 2, λ N, are wavelength converted to the lightwaves whose wavelength are λ N', λ N-1', . . . , λ 1'.

[0103]

[Equation 7]

$$\lambda_p = \frac{1}{2}\left(\frac{\lambda_N \lambda_N'}{\lambda_N + \lambda_N'}\right)$$

[0110]

(Ninth Embodiment of Wavelength Converter)

FIG. 15 shows a wavelength converter according to a ninth embodiment of the present invention. The wavelength converter corresponds to the aforementioned seventh to ninth aspect of the present invention. The wavelength converter appeared in FIG. 15 is an example of the applications of the tenth embodiment. Concerning the WDM lightwaves inputted to the optical divider, wavelength of the lightwaves are put to be .lambda..sub.1, .lambda..sub.2, . . . , .lambda..sub.N, where N is a positive integer. In this wavelength converter, the original WDM lightwaves are divided into three using e.g., an optical star-coupler. The divided lightwaves outputted from the first output port of the optical divider 40 is the WDM lightwaves not required to be wavelength converted. Output lightwaves from the remained port (the second and the third output port of the optical divider are both the WDM lightwaves required to be

wavelength converted. The lightwaves are wavelength converted by the broadband multi-channels simultaneously wavelength conversion portion. Both the wavelength converted lightwaves outputted from the wavelength conversion portion and are combined with the WDM lightwaves outputted from the first output port of the optical divider by an optical combiner.

[0111]

In this case, wavelength of the original WDM lightwaves are put to be $\lambda 1$, $\lambda 2$, . . . , λN, where N is a positive integer. Then putting the wavelength of the wavelengths converted lightwaves outputted from the first broadband multi-channels wavelength conversion portion 10 wavelength as $\lambda N'$, $\lambda N\text{-}1'$, . . . , $\lambda 1'$, the wavelength $\lambda N'$ is the shortest in all of the first wavelength converted lightwaves. Similarly, putting the wavelength of the wavelength converted lightwaves outputted from the second broadband multi-channels wavelength conversion portion 20 wavelength as $\lambda N''$, $\lambda N\text{-}1''$, . . . , $\lambda 1''$, the wavelength $\lambda N''$ is the shortest in all of the second wavelength converted lightwaves. It is essentially required that all the wavelength $\lambda K'$ (K'=1,2, . . . , N) must not be coincided with any $\lambda K''$(K'=1,2, . . . , N). For example, in order to satisfy the requirement it is possible to design the wavelength conversion portion 20 for satisfying the condition: $\lambda 1' < \lambda N''$. Pump wavelength of the first wavelength portion ($\lambda p1$) and second wavelength portion ($\lambda p2$) is determined by the frequency phase-matching condition and are provided as follows:

[0112]

[Equation 8]

$$\lambda_{p1} = \frac{1}{2}\left(\frac{\lambda_N \lambda_N'}{\lambda_N + \lambda_N'}\right)$$

[0113]

[Equation 9]

$$\lambda_{p2} = \frac{1}{2}\left(\frac{\lambda_N \lambda_N''}{\lambda_N + \lambda_N''}\right)$$

[0114]

From the propagation constant phase-matching condition, zero-dispersion wavelength of the optical fiber in the first and second wavelength conversion portion must be in the vicinity of the .lambda..sub.p1 and .lambda..sub.p2 respectively. By satisfying all the above conditions, it is possible to configure any wavelength of the lightwaves in three WDM lightwaves before combining the optical combiner 41 is not duplicated in the wavelength domain.

[0120]

(Tenth Embodiment of Wavelength Converter)

FIG. 16 shows a wavelength converter according to a tenth embodiment of the present invention. The wavelength converter corresponds to an alternation as shown in FIG. 1 except the filter 1. According to the wavelength converter appeared in FIG. 16, lightwaves required to be wavelength converted are filtered out from the WDM lightwaves inputted to the wavelength converter by an optical band-pass filter. The filtered out lightwaves in the sub-band is the lightwaves required to be wavelength converted, and are combined with the pump light from the pump source 2 by an optical combiner 3. The combined lightwaves are launched into the optical fiber 4 and the wavelength converted lightwaves are generated by FWM in the fiber 4. Solely the wavelength converted lightwaves are filtered out from the lightwaves output from the optical fiber 4 by an optical filter 5. Consequently, the lightwaves required to be wavelength converted that are outputted from the optical filter 37, are simultaneously wavelength converted by the wavelength conversion portion 10. The wavelength converted lightwaves outputted from the wavelength conversion portion 10 are combined with the lightwaves not required to be wavelength converted that are outputted from the optical filter 37, by an optical combiner 6 without duplication in wavelength domain. The combined lightwaves are outputted from the wavelength converter. As a resultant of the wavelength conversion processes of the wavelength converter, as shown in FIG. 15, one sub-band of the original WDM lightwaves is wavelength converted simultaneously to the outside of the full band of the original WDM lightwaves in the wavelength domain by the wavelength converter described in this embodiment. The optical fiber 4 shown in FIG. 16 can be replaced to an SOA.

[0130]

(First Embodiment of Wavelength-Division Multiplexing Transmission Method)

FIG. 17 and 18 show an embodiment of a wavelength-division multiplexing method corresponding to the aforementioned tenth to twelfth aspect of the method in the present invention.

[0131]

Concerning the following high capacity and long distance WDM communication systems: A trunk line is composed of the conventional single-mode fiber (referred as SMF hereafter) and dispersion compensating fibers, e.g., Reverse-Dispersion Fiber (referred as RDF hereafter). Efficiency of the so-called transmission line composed of the Dispersion Managed line (referred as DM line hereafter), e.g., transmission line composed of the SMF and RDF, are verified experimentally. Under the optimized design of the DM line, the transmission line can suppress the noise from the inter-channel crosstalk due to inter-channel FWM.

[0132]

On the contrary of such efficiency of the DM line, the transmission line composed of the conventional dispersion-shifted fiber (referred as DSF line hereafter) that is more influenced by the FWM than the DM line, are sometimes used in the metropolitan area network since the metropolitan area network is not required such a high-capacity transmission in comparison of the trunk line. In general, the frequency interval of the WDM signals transmitted in the metropolitan area network, are broader than the interval of the trunk line, and furthermore the bit-rate of the signals per channel is smaller than the bit-rate of the trunk line. In the above circumstances, the WDM signals transmitted to the trunk line cannot be dropped to the metropolitan line directly with preserving the frequency intervals of the WDM signals. The inter-channel FWM will deteriorate the signal to noise ratio because of the difference of the influence of the crosstalk due to FWM. The wavelength converter provided in the aforementioned third and fourth aspects of the present invention resolve the problem. The wavelength converter provided the third and fourth aspects of the present invention can broaden the frequency interval of the WDM signals inputted to the wavelength converter. Thus under the optimized design of the wavelength converter, the influences of the FWM induced

inter-channel crosstalk is negligible in spite of the use of the DSF line.

[0133]

Transfer of the WDM signals from a metropolitan area network to the trunk line is also required. In the case, WDM signals processing opposite to the above is necessary. Namely, the frequency interval of the WDM signals from the metropolitan network is required to be narrower in order to transfer the signals to the trunk line without lack of the efficiency of the DM line used to the trunk line. Otherwise the advantages of the DM line are not utilized sufficiently. To resolve the problem, the wavelength converter provided in the aforementioned fifth and sixth aspects of the present invention are applicable. The wavelength converter provided the fifth and sixth aspects of the present invention can reduce the frequency interval of the WDM signals input to the wavelength converter. Thus the influences of the FWM induced inter-channel crosstalk is increased as large as the DM line (SMF+RDF) can compensate for.

[0134]

An optical add-drop multiplexer/demultiplexer (OADM) applicable to connect the trunk line and the metropolitan area network (or equivalently, DM line and DSF line) can realize the above two functionality. The wavelength converter provided in the second or sixth embodiment (or sixth or ninth embodiment) can connect the trunk line and the metropolitan area network by avoiding the problems discussed above. In FIG. 18, OXC is used as an acronym of the Optical Cross Connect.

[0140]

[Effect of the Invention]

The wavelength converter according to the present invention has the following effects:

1. Solely the lightwaves required to be wavelength converted are filtered out from all the input broadband WDM lightwaves, and then be wavelength converted simultaneously by use of the FWM.

2. WDM lightwaves reconfigured by the wavelength conversion from the input WDM lightwaves in wavelength domain are combined with the lightwaves all of whose wavelength is not coincided with the any of the wavelength of the reconfigured WDM lightwaves to obtain an alternative WDM lightwaves.

3. Since the frequency interval of the WDM lightwaves can be broaden or

be reduced, the two WDM system with different transmission capacities can be connected together by spending low cost, and the optical interconnection between the two systems can be realized without lack of the advantages of each system.

[0141]

The wavelength-division multiplexing transmission method according to the present invention has the following effects:

1. By utilizing the flexibility of the FWM based multi-channels simultaneous wavelength converter according to the present invention, flexible WDM networks can be realized.

2. By utilizing the wavelength converter according to the present invention, interconnection of the independently designed two WDM systems can be realized.

3. By utilizing the wavelength converter according to the present invention, frequency interval of the WDM signals can be changed to optimize the transmission capacity of the transmission line, and therefore WDM signals can be added or dropped between two independent transmission lines without lack of the advantages of the two lines.

[BRIEF DESCRIPTION OF THE DRAWINGS]

FIG. 1 is an explanatory schematic showing a wavelength converter according to a first embodiment of the present invention;

FIG. 2 is an explanatory schematic showing a wavelength converter according to a second embodiment of the present invention;

FIG. 3 is a view for explaining wavelength conversion procedures of lightwaves in the second wavelength converter shown in FIG. 2;

FIG. 4 is an explanatory schematic showing a wavelength converter according to a third embodiment of the present invention;

FIG. 5 is a view for explaining wavelength conversion procedures of lightwaves in the third wavelength converter shown in FIG. 4;

FIG. 6 is an explanatory schematic showing a wavelength converter according to a fourth embodiment of the present invention;

FIG. 7 is a view for explaining wavelength conversion procedures of lightwaves in the wavelength conversion shown in FIG. 6;

FIG. 8 is an explanatory schematic showing a wavelength converter according to a fifth embodiment of the present invention;

FIG. 9 is a view for explaining wavelength conversion procedures

of lightwaves in the wavelength converter shown in FIG. 8;

FIG. 10 is an explanatory schematic showing a wavelength converter according to a sixth embodiment of the present invention;

FIG. 11 is an explanatory view showing the wavelength converter according to the seventh embodiment of the present invention;

FIG. 12 is a view for explaining wavelength conversion procedures of lightwaves in the wavelength converter shown in FIG. 11;

FIG. 13 is an explanatory view showing the wavelength converter according to the eighth embodiment of the present invention;

FIG. 14 is a view for explaining wavelength conversion procedures of lightwaves in the wavelength converter shown in FIG. 13;

FIG. 15 is an explanatory view showing the wavelength converter according to the ninth embodiment of the present invention;

FIG. 16 is an explanatory view showing the wavelength converter according to the tenth embodiment of the present invention;

FIG. 17 is an explanatory schematic showing a WDM transmission method according to an embodiment of the present invention; and

FIG. 18 is a view for explaining usage of optical add-drop multiplexers shown in FIG. 17.

[DESCRIPTION OF REFERENCE NUMERAL]

1 optical filter
2 pump source
3 optical combiner
4 optical fiber
5 optical filter
6 optical combiner
10 multi-channels simultaneous wavelength conversion portion
11 etalon filter
12 second optical coupler
13 second pump source
15 second fiber
16 second filter
17 third optical coupler
30 wavelength converter
31 arrayed waveguide grating
41 second filter

42	second pump source
43	second coupler
44	second fiber
45	second filter
48	third coupler
51	optical coupler
53	second optical coupler
61	star-coupler
62	second star-coupler
63	wavelength converter
64	second wavelength converter

[Name of the document]
ABSTRACT
[Summary]
[Problem to be solved]
[Means to solve the problem]

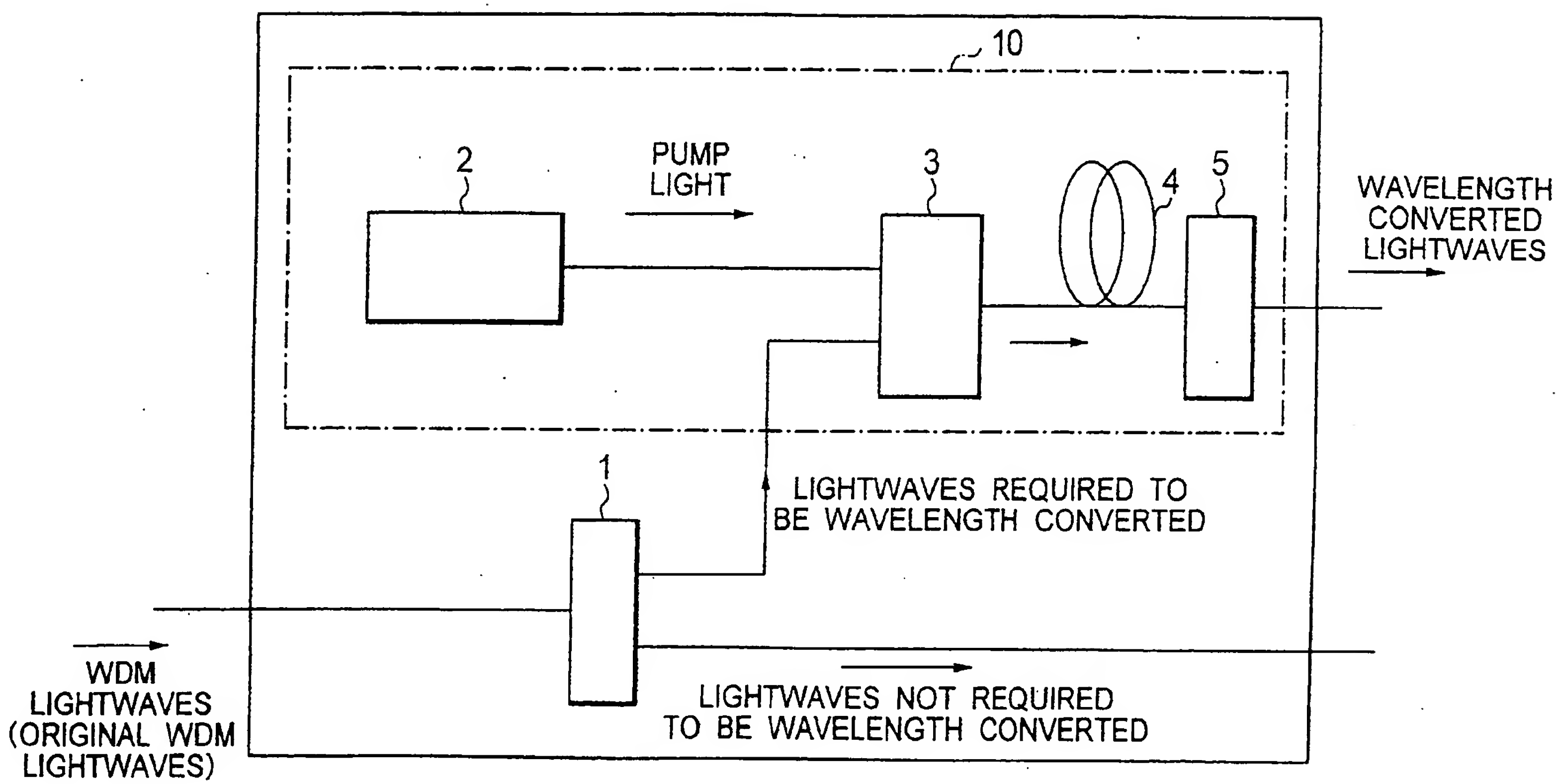

10
2
PUMP LIGHT
3
4
5
WAVELENGTH CONVERTED LIGHTWAVES
1
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED

FIG. 1

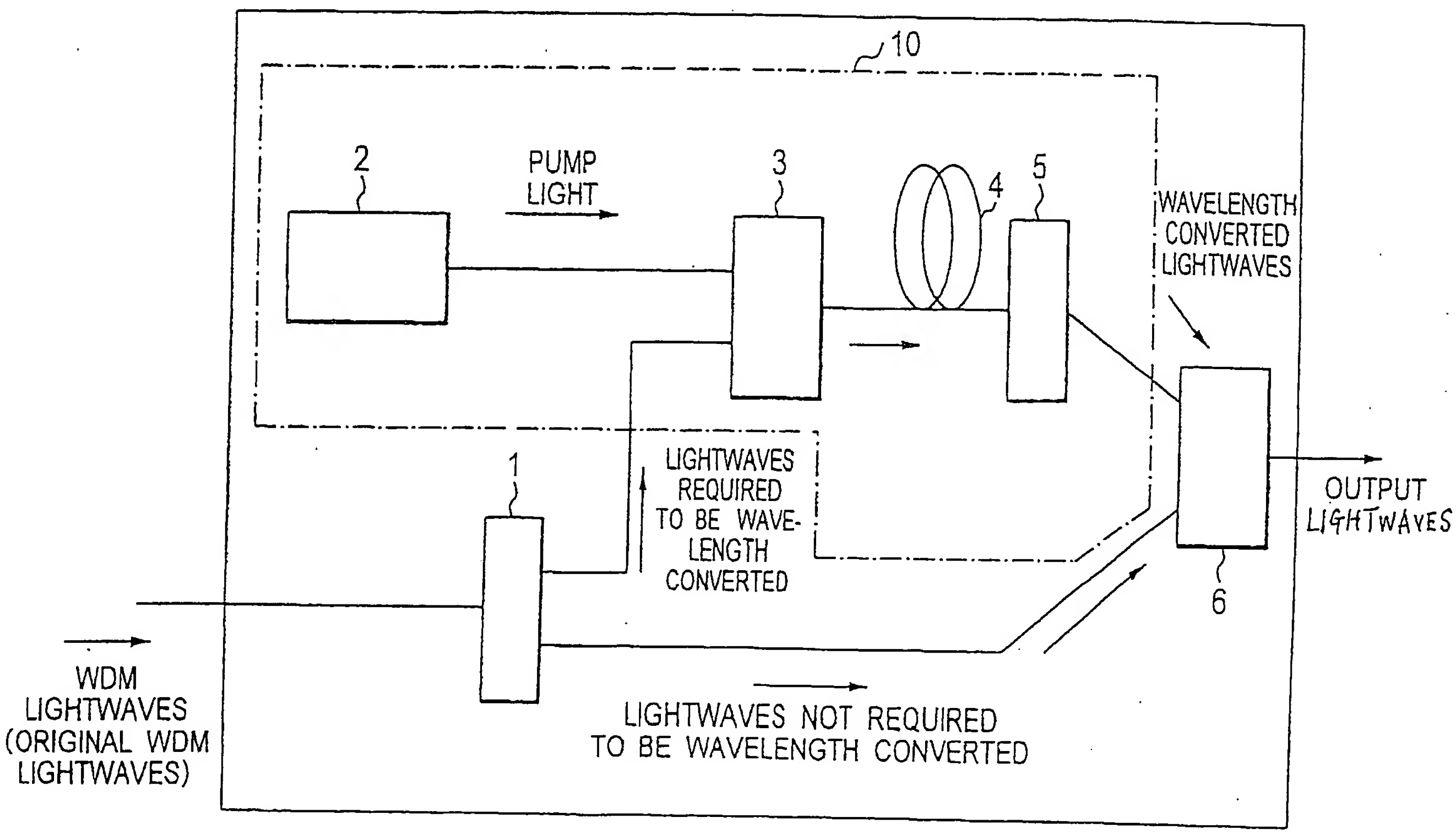

10
2
PUMP LIGHT
3
4
5
WAVELENGTH CONVERTED LIGHTWAVES
1
LIGHTWAVES REQUIRED TO BE WAVE-LENGTH CONVERTED
OUTPUT LIGHTWAVES
6
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED

FIG. 2

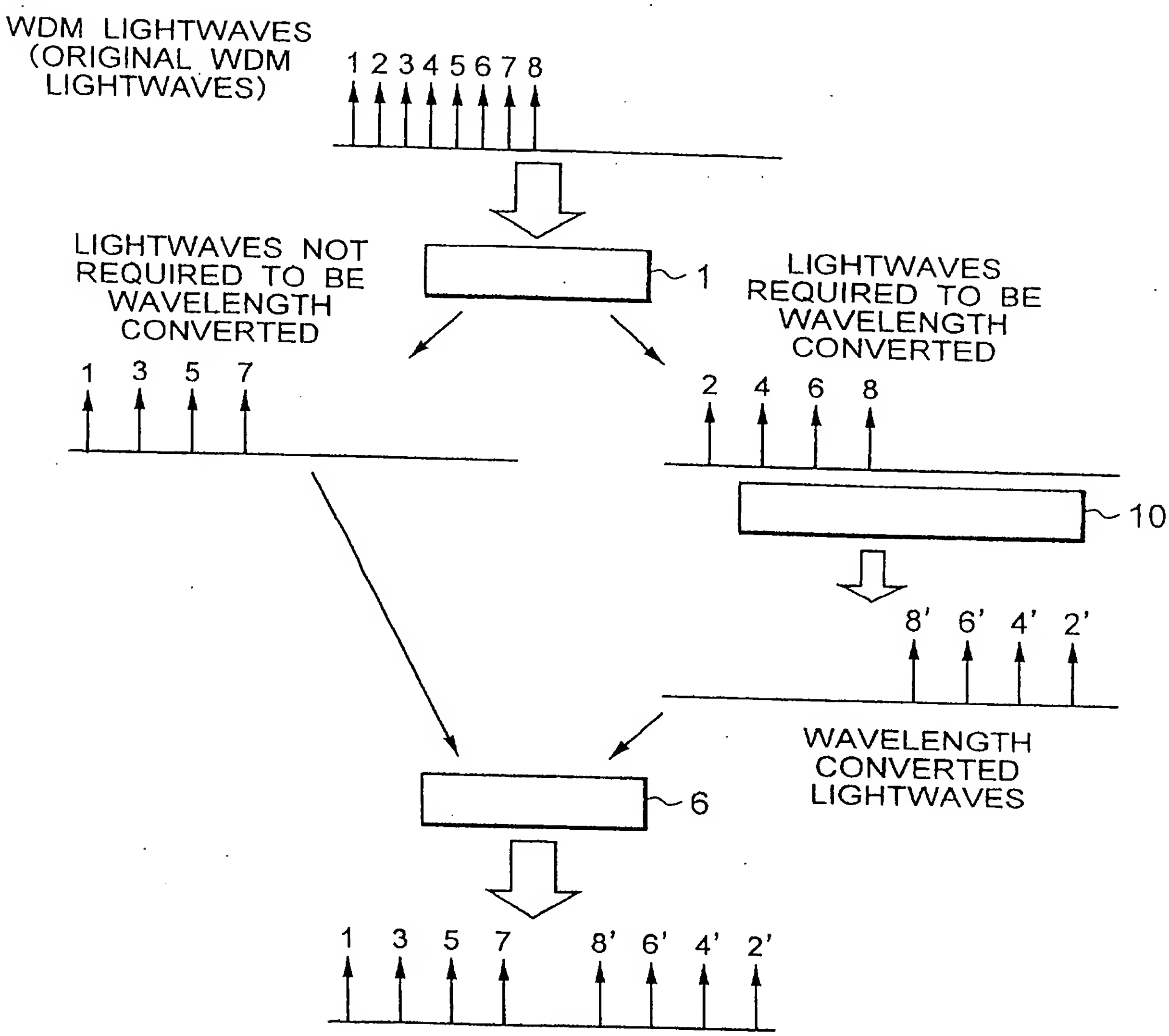

WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
1 2 3 4 5 6 7 8
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
1
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
1 3 5 7
2 4 6 8
10
8' 6' 4' 2'
WAVELENGTH CONVERTED LIGHTWAVES
6
1 3 5 7 8' 6' 4' 2'

FIG. 3

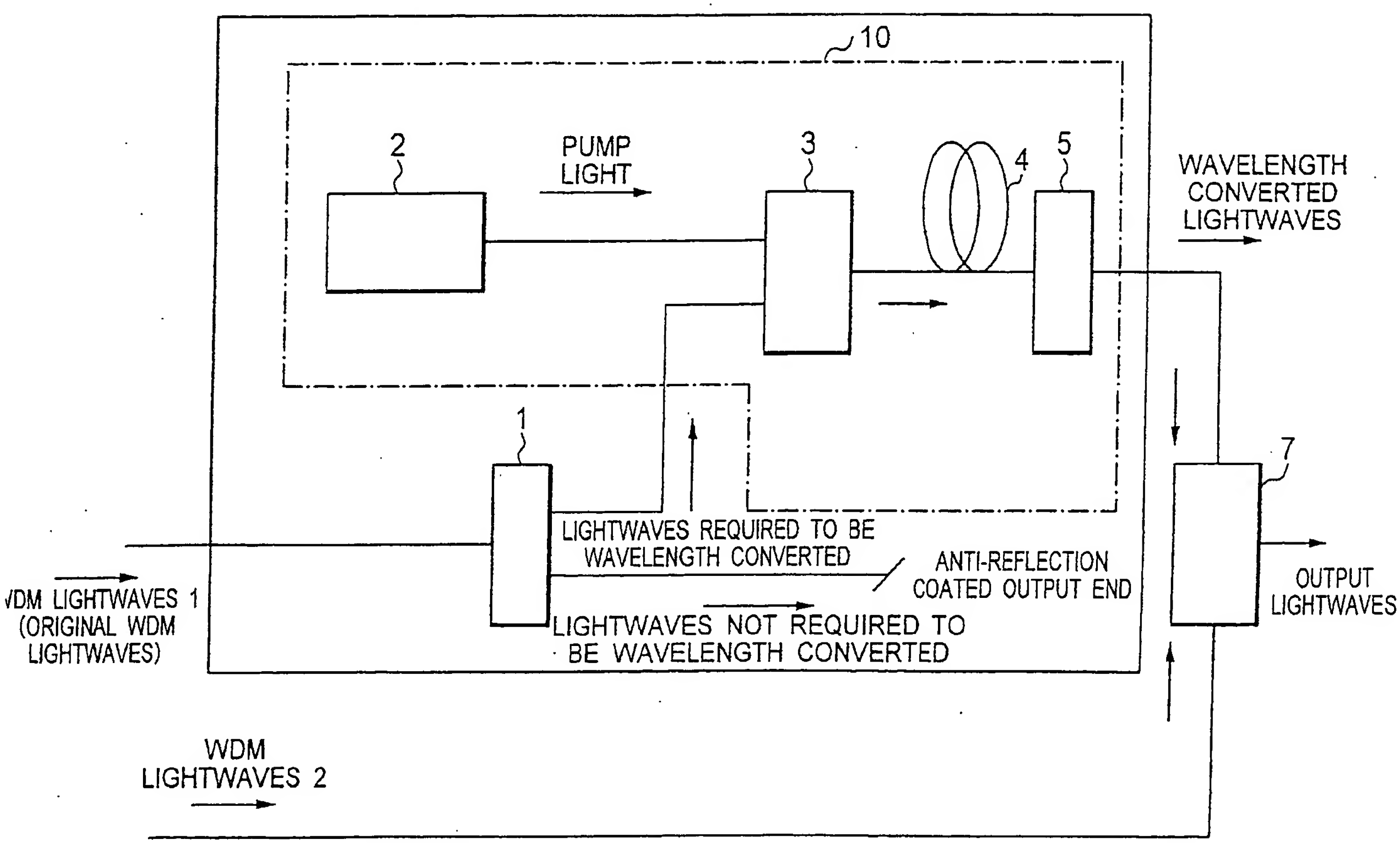
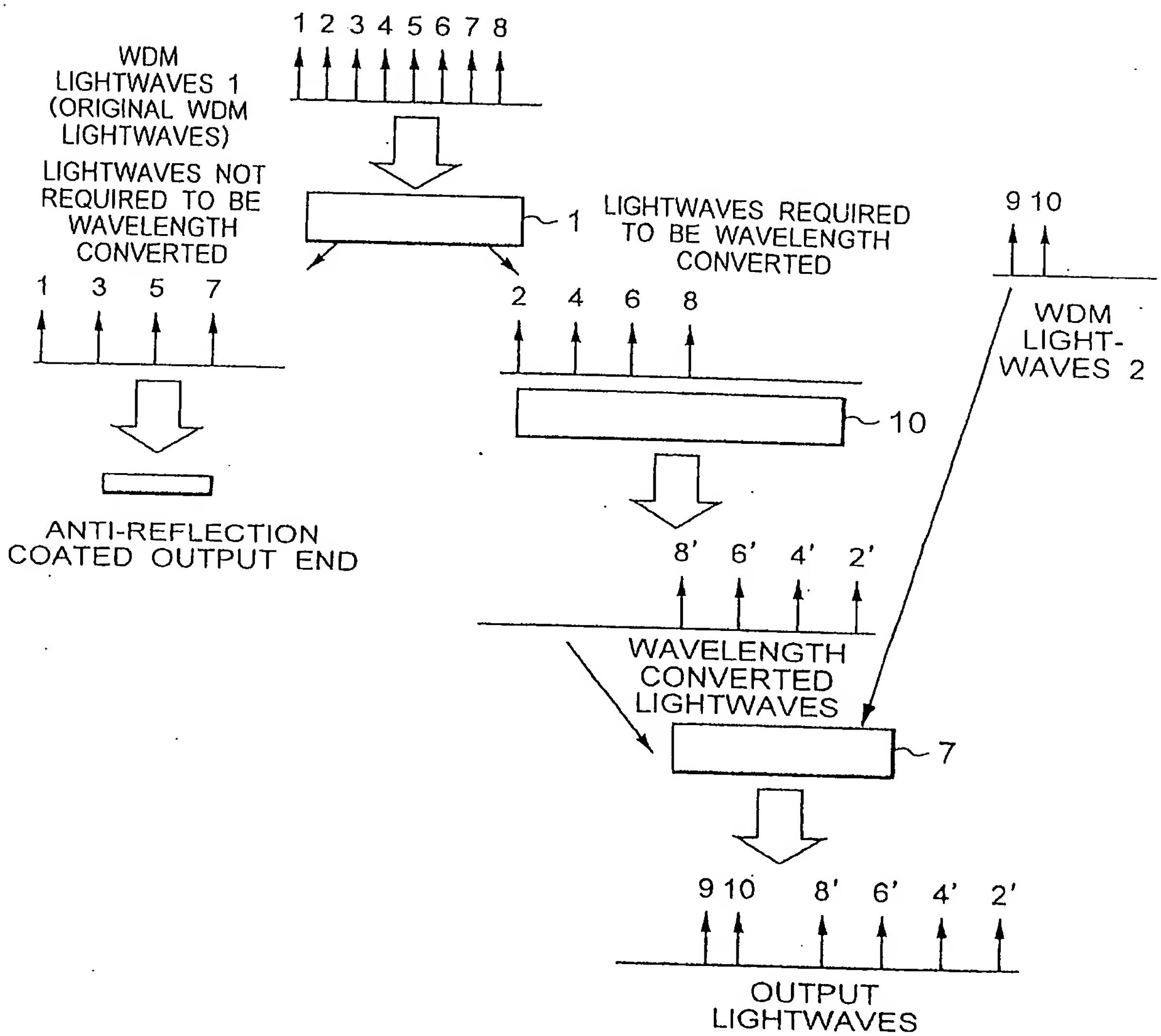

10
2
PUMP
LIGHT
3
4
5
WAVELENGTH
CONVERTED
LIGHTWAVES
1
7
LIGHTWAVES REQUIRED TO BE
WAVELENGTH CONVERTED
ANTI-REFLECTION
COATED OUTPUT END
VDM LIGHTWAVES 1
(ORIGINAL WDM
LIGHTWAVES)
LIGHTWAVES NOT REQUIRED TO
BE WAVELENGTH CONVERTED
OUTPUT
LIGHTWAVES
WDM
LIGHTWAVES 2

FIG. 4



1 2 3 4 5 6 7 8
WDM LIGHTWAVES 1 (ORIGINAL WDM LIGHTWAVES)
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
1
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
9 10
1 3 5 7
2 4 6 8
WDM LIGHT-WAVES 2
10
ANTI-REFLECTION COATED OUTPUT END
8' 6' 4' 2'
WAVELENGTH CONVERTED LIGHTWAVES
7
9 10 8' 6' 4' 2'
OUTPUT LIGHTWAVES

FIG. 5

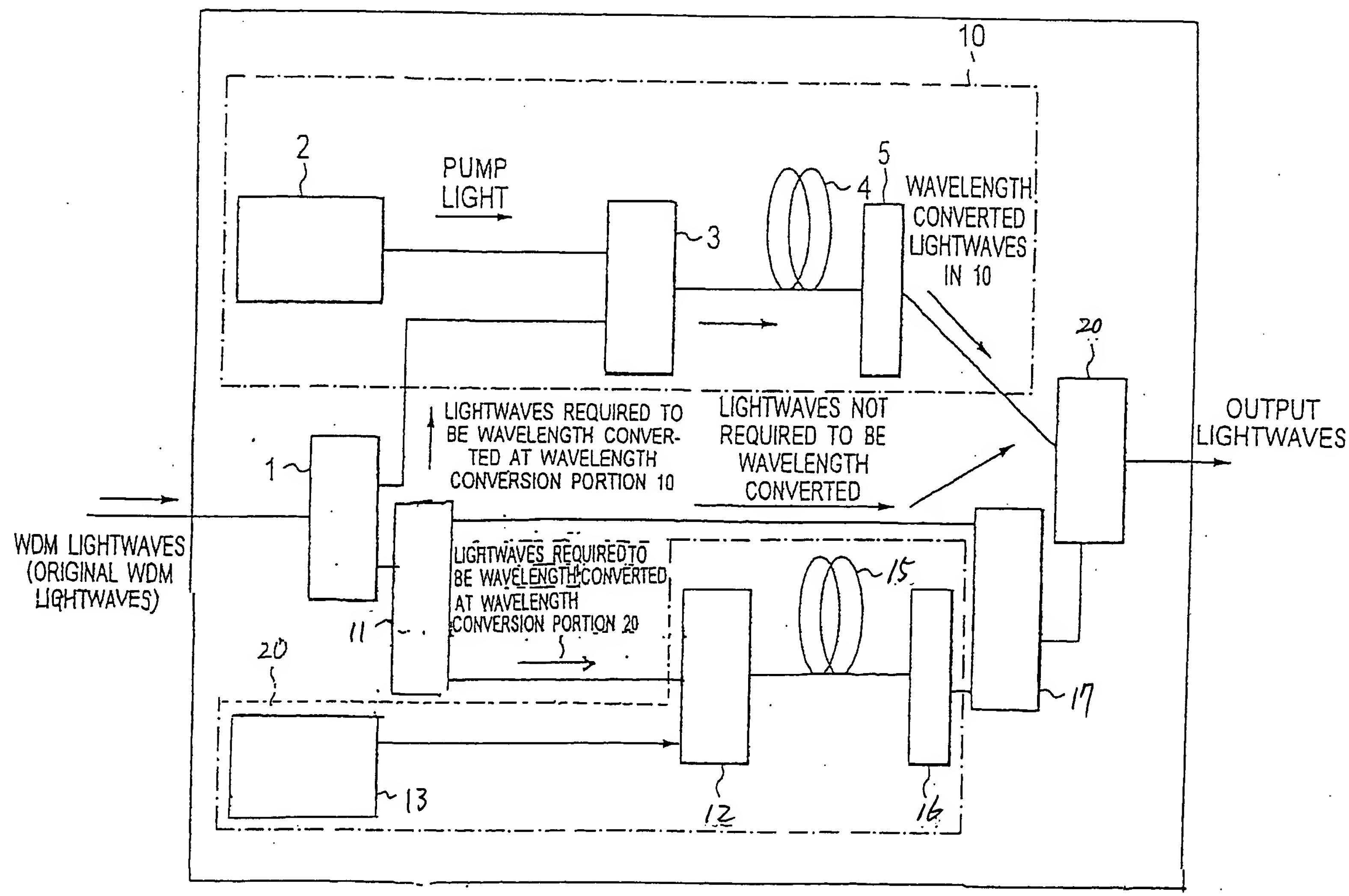

10
2
PUMP LIGHT
3
4
5
WAVELENGTH CONVERTED LIGHTWAVES IN 10
20
OUTPUT LIGHTWAVES
1
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 10
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 20
15
11
20
17
13
12
16

FIG. 6

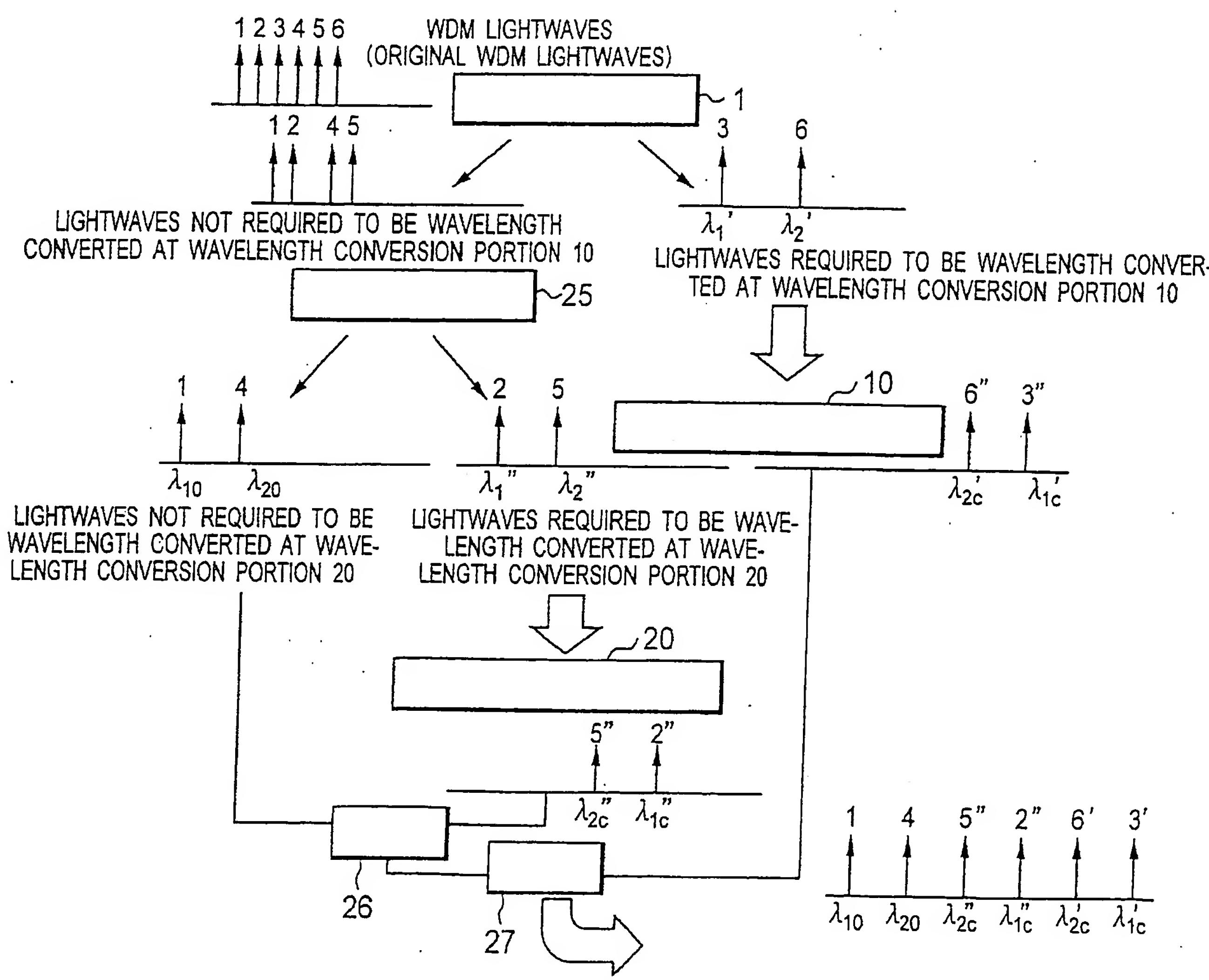

1 2 3 4 5 6
WDM LIGHTWAVES
(ORIGINAL WDM LIGHTWAVES)
1
1 2 4 5
3 6
λ1' λ2'
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 10
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 10
25
10
1 4
λ10 λ20
2 5
λ1" λ2"
6" 3"
λ2c' λ1c'
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 20
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 20
20
5" 2"
λ2c" λ1c"
26
27
1 4 5" 2" 6' 3'
λ10 λ20 λ2c" λ1c" λ2c' λ1c'

FIG. 7

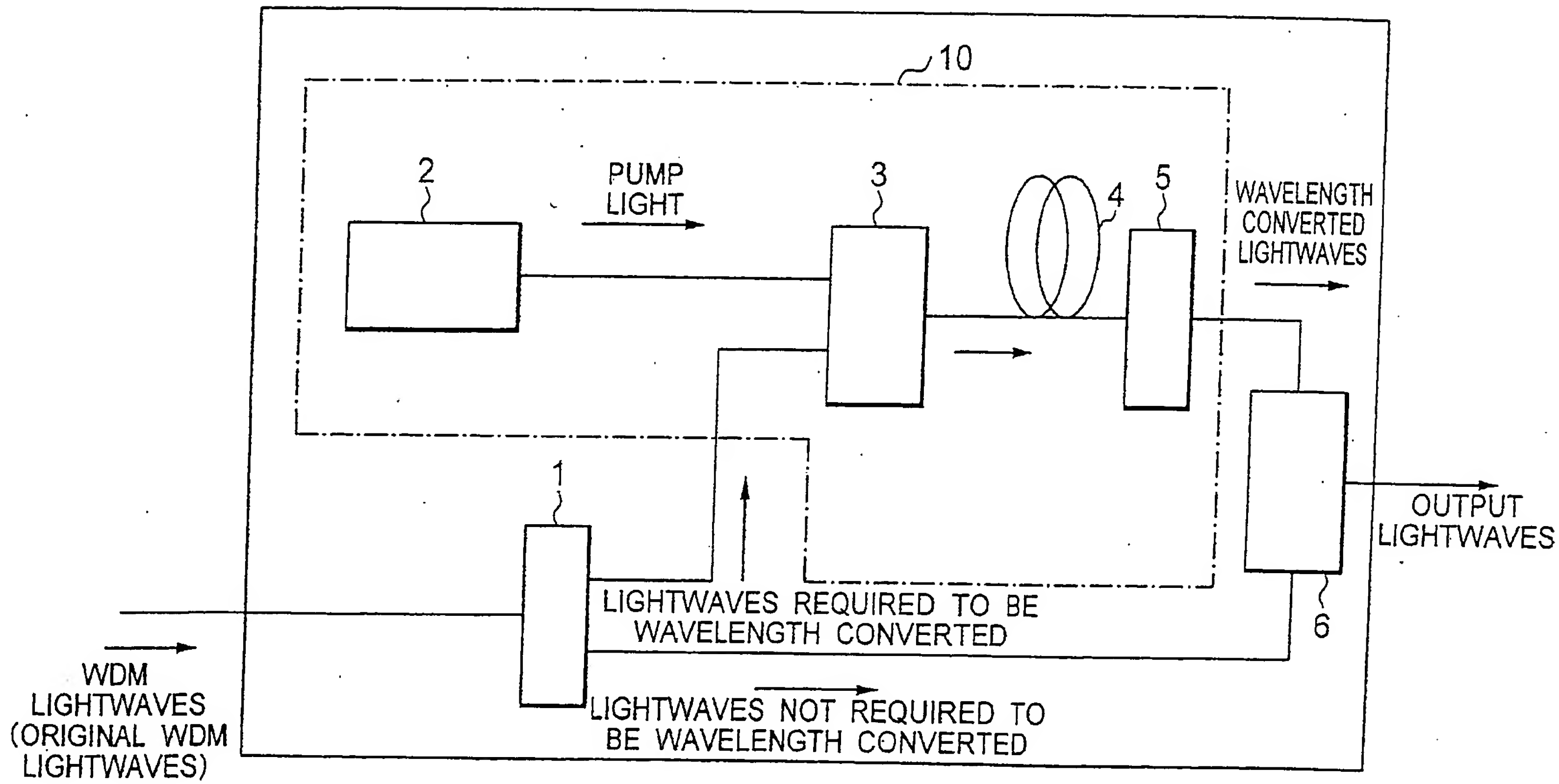
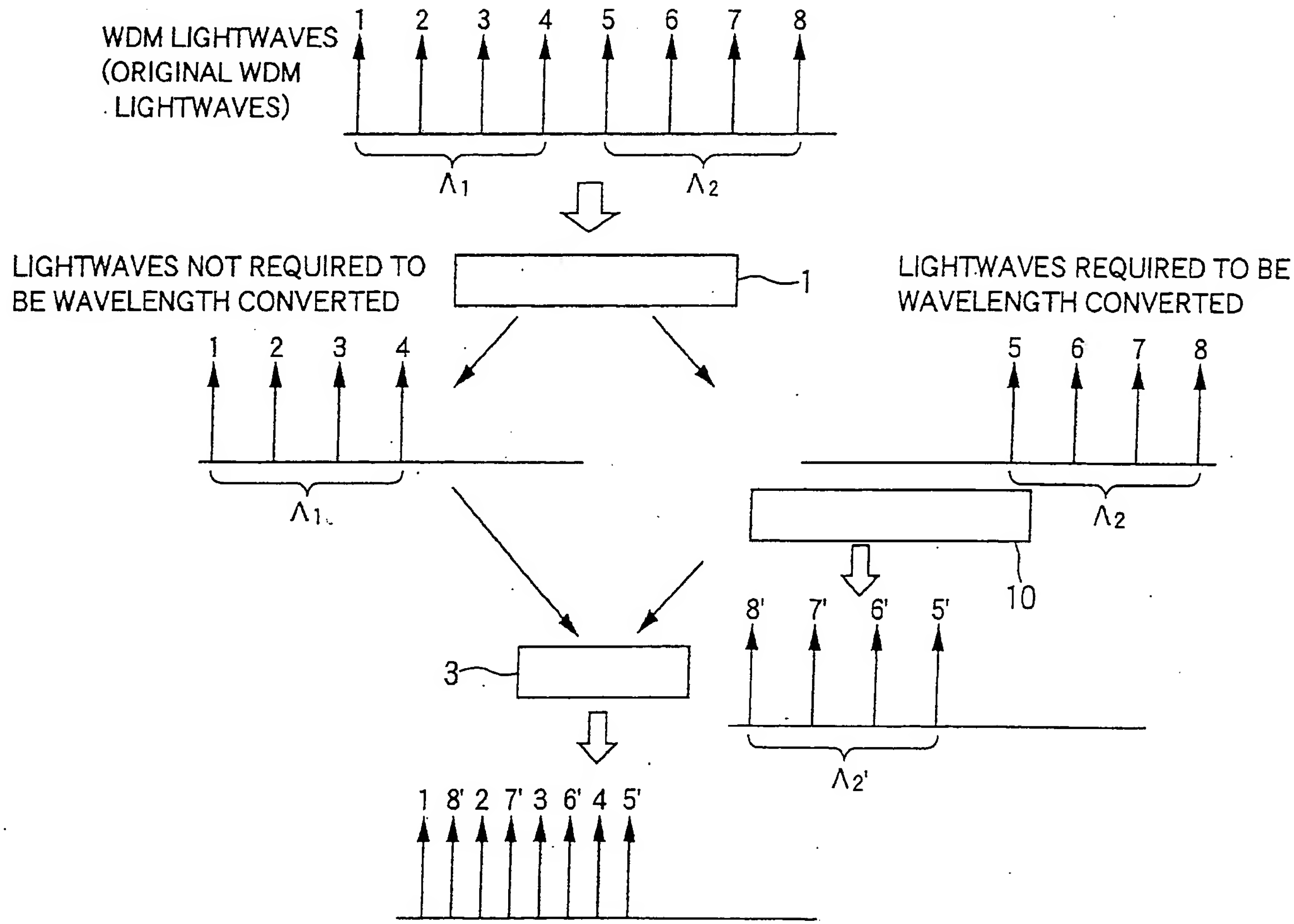

10
2
PUMP LIGHT
3
4
5
WAVELENGTH CONVERTED LIGHTWAVES
1
6
OUTPUT LIGHTWAVES
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)

FIG. 8



WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
1 2 3 4 5 6 7 8
Λ1
Λ2
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
1
1 2 3 4
Λ1
5 6 7 8
Λ2
10
8' 7' 6' 5'
Λ2'
3
1 8' 2 7' 3 6' 4 5'

FIG. 9

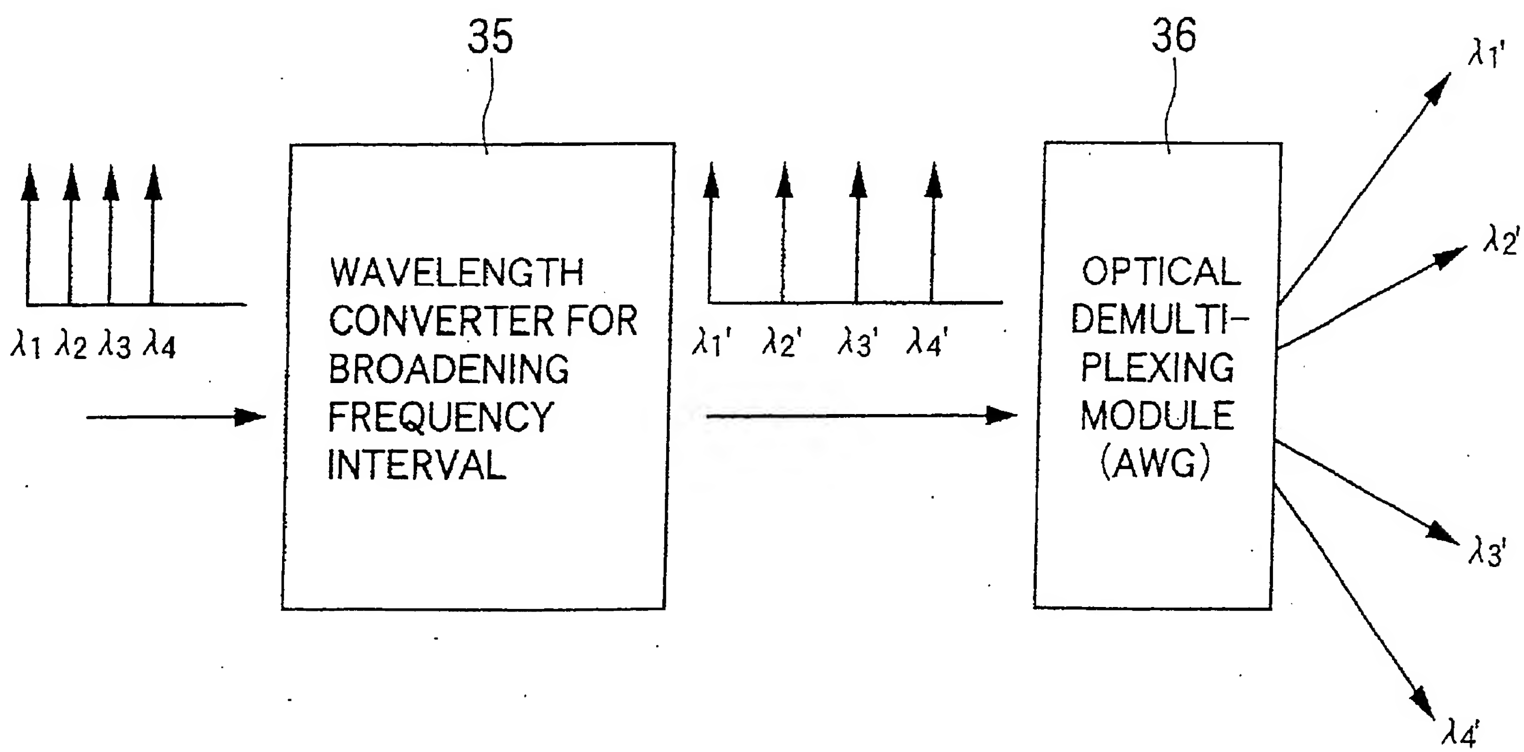

35
36
λ1 λ2 λ3 λ4
WAVELENGTH CONVERTER FOR BROADENING FREQUENCY INTERVAL
λ1' λ2' λ3' λ4'
OPTICAL DEMULTI- PLEXING MODULE (AWG)
λ1'
λ2'
λ3'
λ4'

FIG. 10

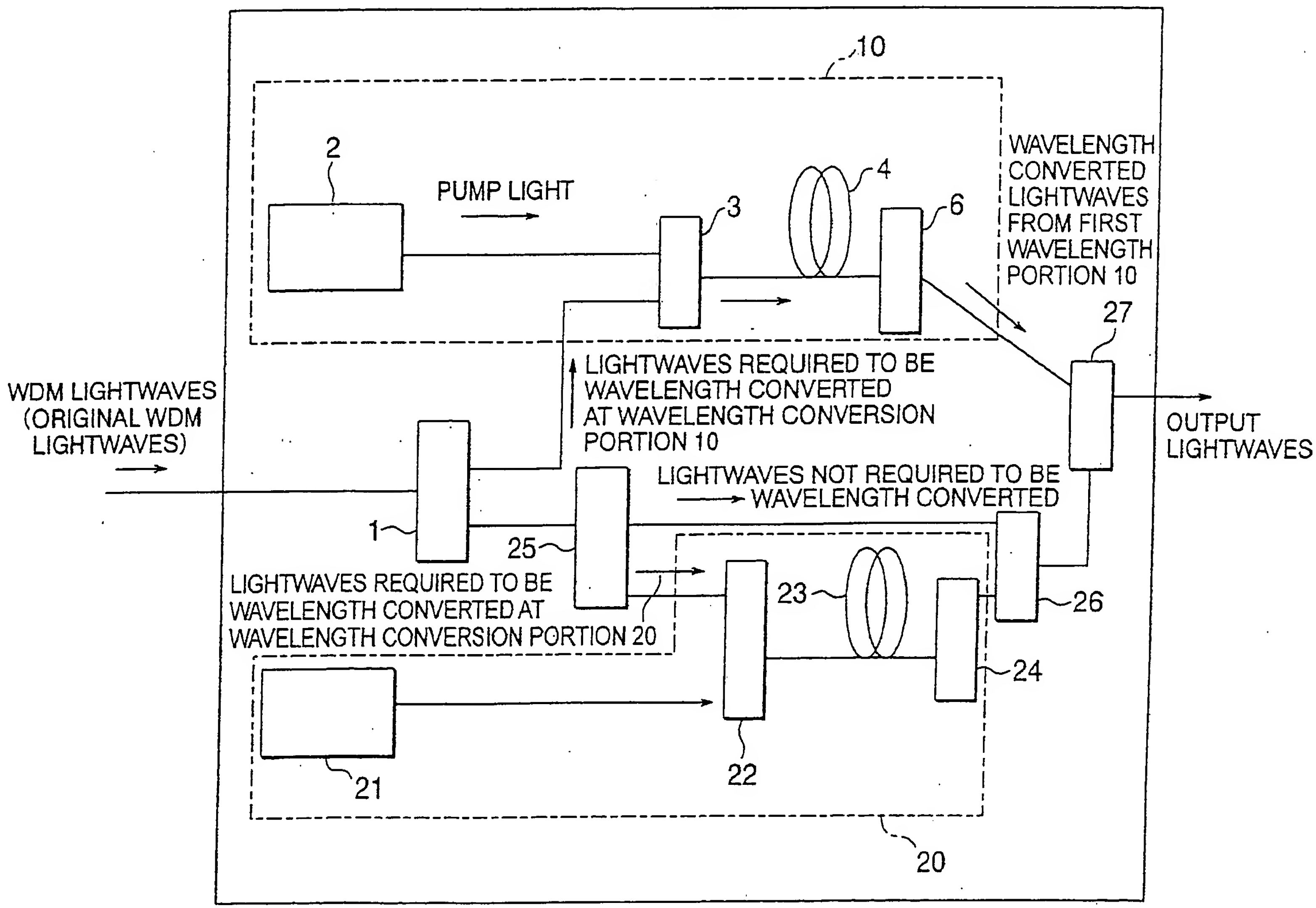

10
2
PUMP LIGHT
3
4
6
WAVELENGTH CONVERTED LIGHTWAVES FROM FIRST WAVELENGTH PORTION 10
27
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 10
OUTPUT LIGHTWAVES
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
1
25
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 20
23
26
24
21
22
20

FIG. 11

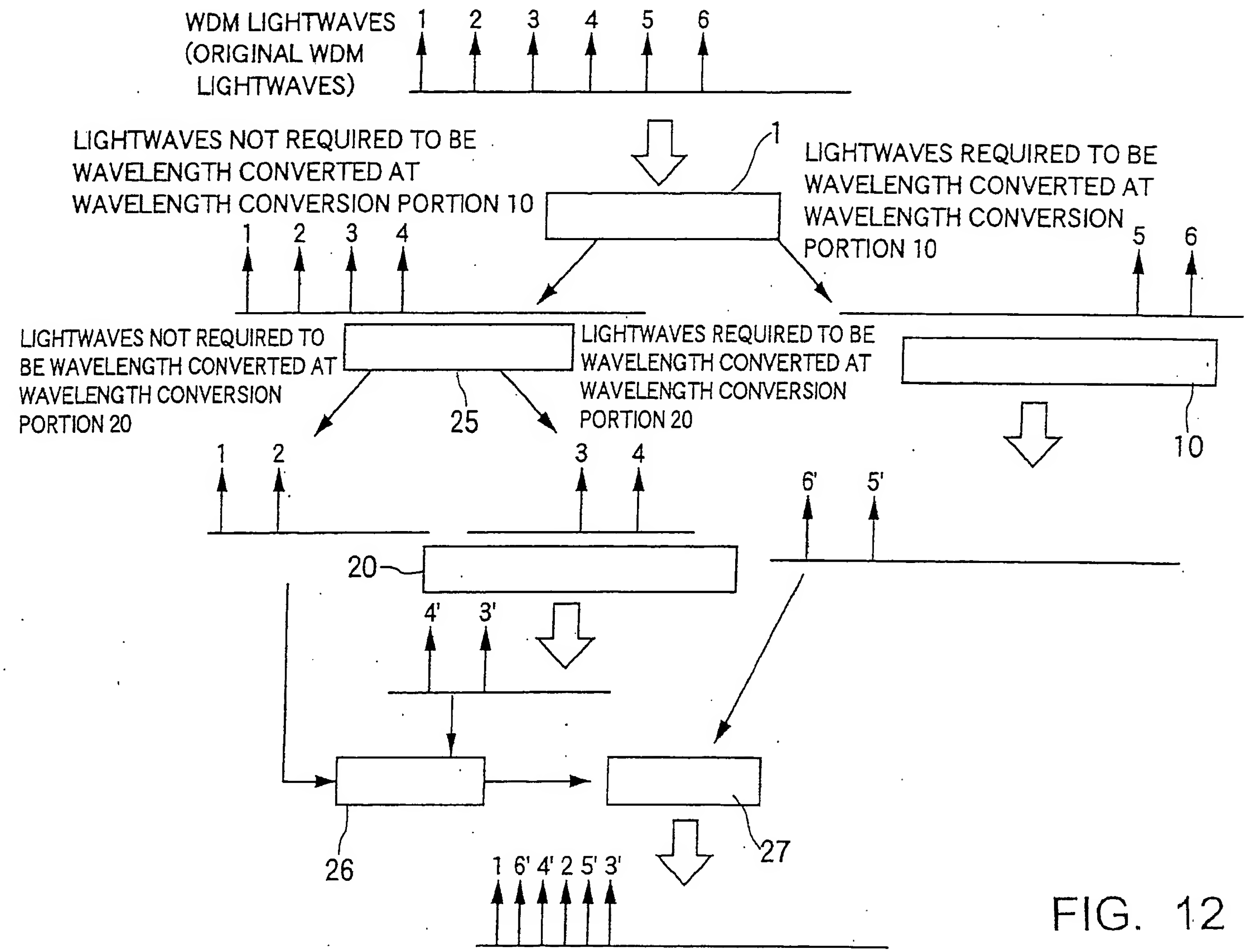

WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
1 2 3 4 5 6
1
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 10
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 10
1 2 3 4
5 6
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 20
25
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED AT WAVELENGTH CONVERSION PORTION 20
10
1 2
3 4
6' 5'
20
4' 3'
26
27
1 6' 4' 2 5' 3'

FIG. 12

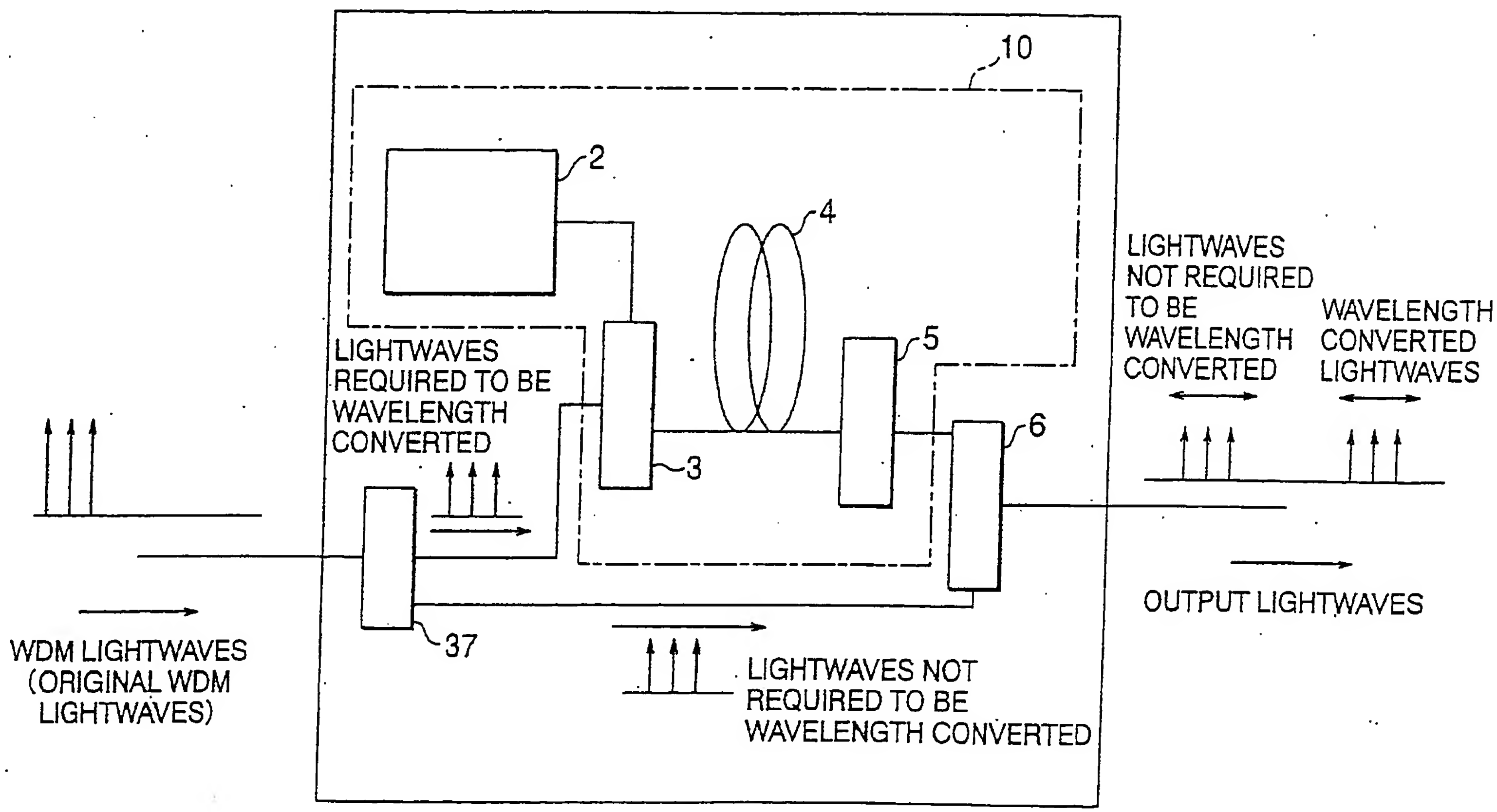

10
2
4
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
WAVELENGTH CONVERTED LIGHTWAVES
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
5
6
3
OUTPUT LIGHTWAVES
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
37
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED

FIG. 13

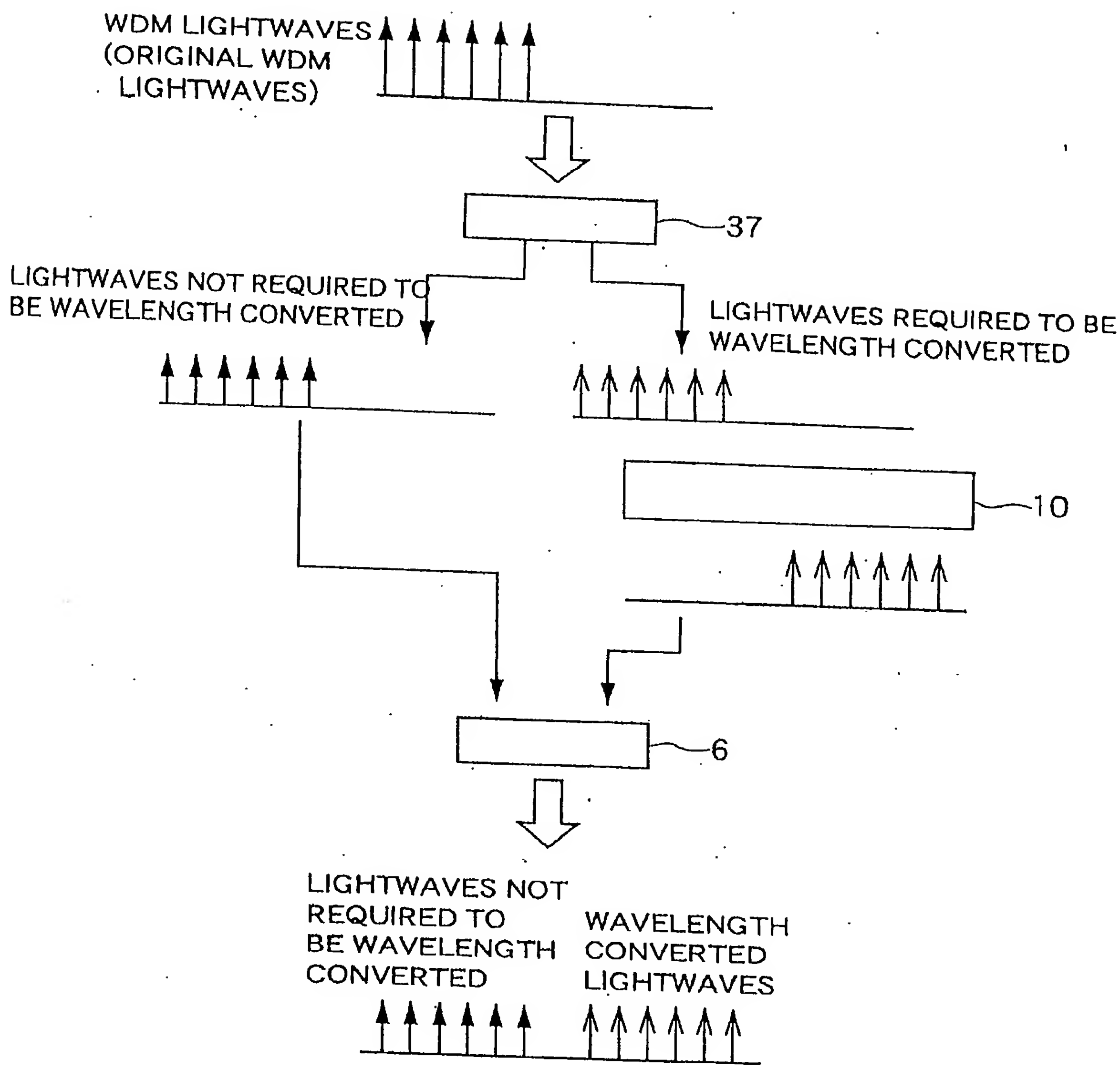

WDM LIGHTWAVES
(ORIGINAL WDM
LIGHTWAVES)
37
LIGHTWAVES NOT REQUIRED TO
BE WAVELENGTH CONVERTED
LIGHTWAVES REQUIRED TO BE
WAVELENGTH CONVERTED
10
6
LIGHTWAVES NOT
REQUIRED TO
BE WAVELENGTH
CONVERTED
WAVELENGTH
CONVERTED
LIGHTWAVES

FIG. 14

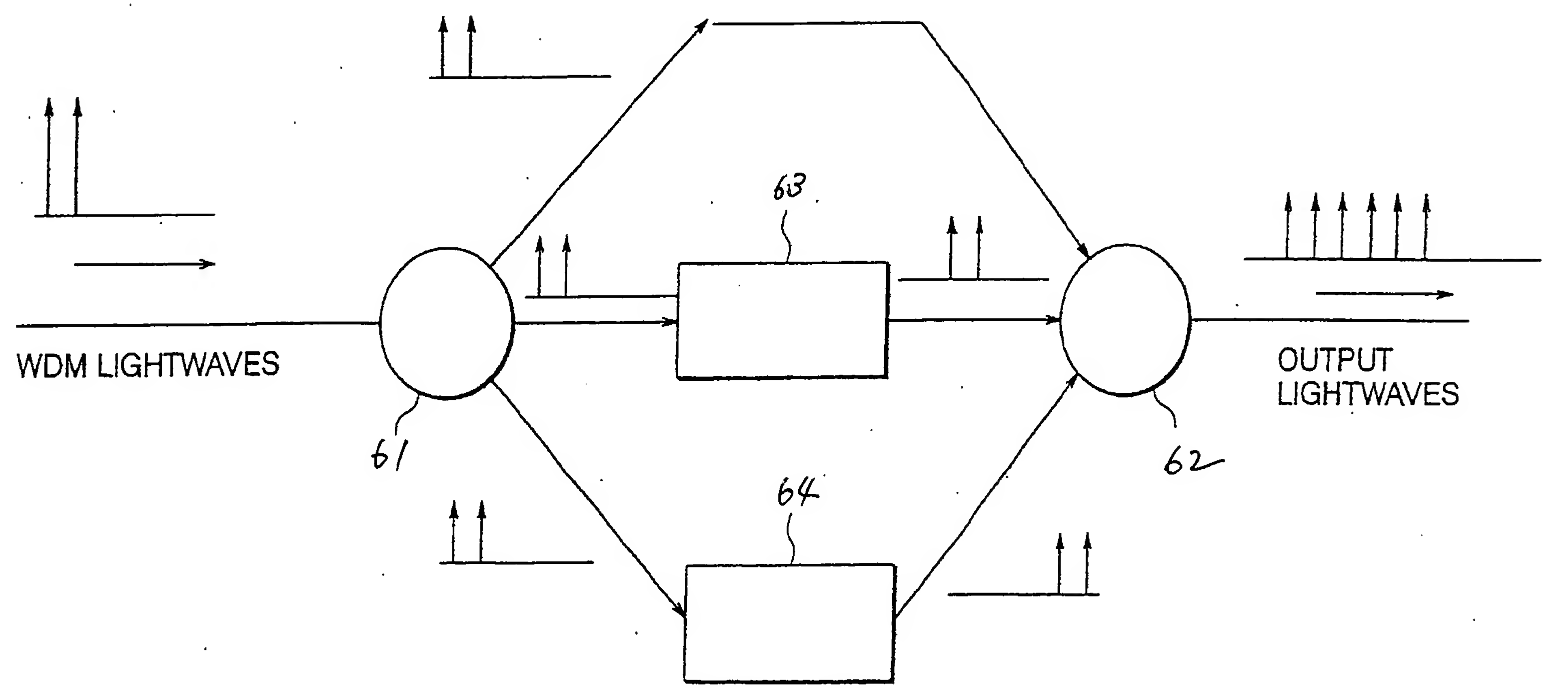
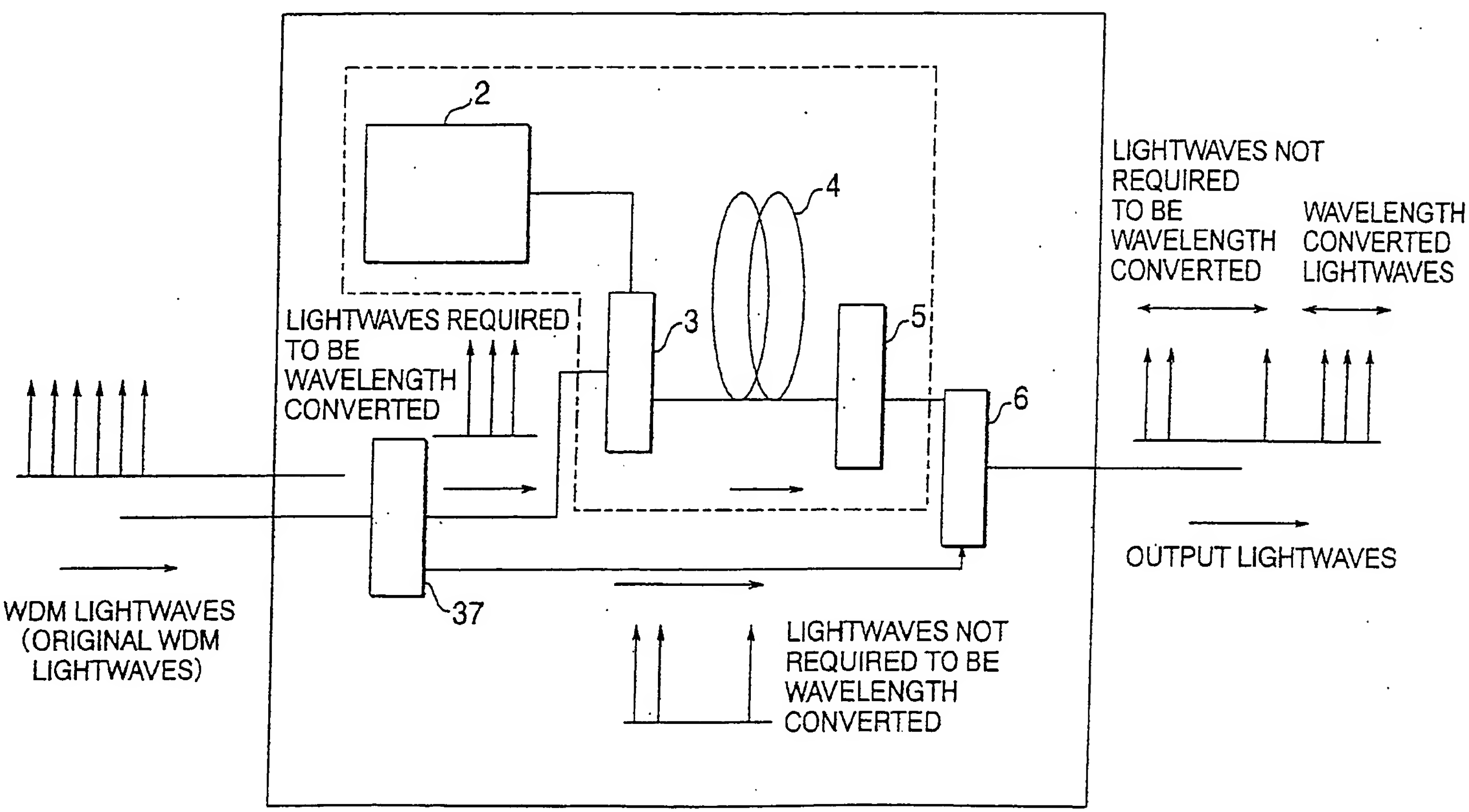


FIG. 15



2
4
3
5
6
37
LIGHTWAVES REQUIRED TO BE WAVELENGTH CONVERTED
WDM LIGHTWAVES (ORIGINAL WDM LIGHTWAVES)
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
LIGHTWAVES NOT REQUIRED TO BE WAVELENGTH CONVERTED
WAVELENGTH CONVERTED LIGHTWAVES
OUTPUT LIGHTWAVES

FIG. 16

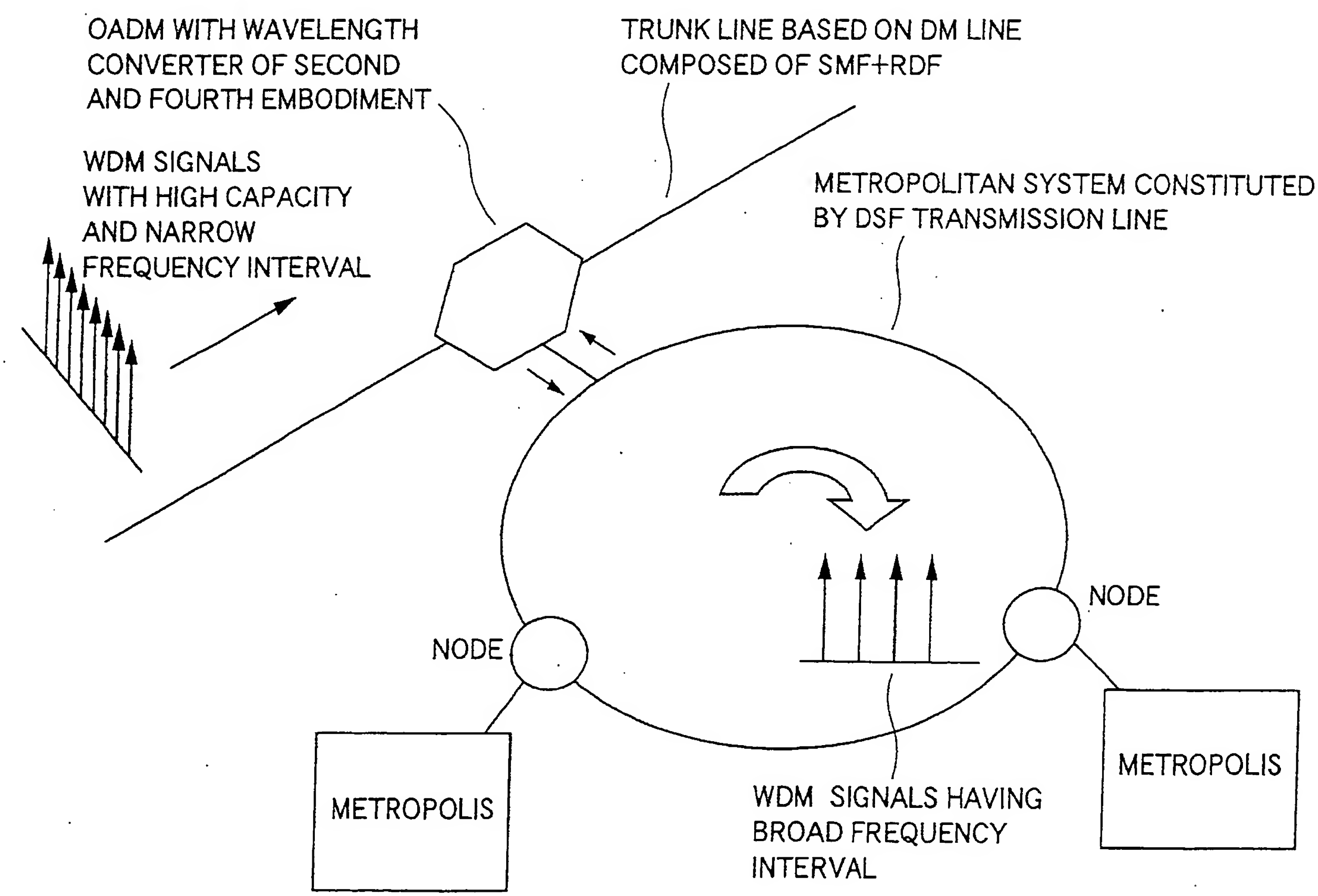

OADM WITH WAVELENGTH CONVERTER OF SECOND AND FOURTH EMBODIMENT
TRUNK LINE BASED ON DM LINE COMPOSED OF SMF+RDF
WDM SIGNALS WITH HIGH CAPACITY AND NARROW FREQUENCY INTERVAL
METROPOLITAN SYSTEM CONSTITUTED BY DSF TRANSMISSION LINE
NODE
NODE
METROPOLIS
METROPOLIS
WDM SIGNALS HAVING BROAD FREQUENCY INTERVAL

FIG. 17

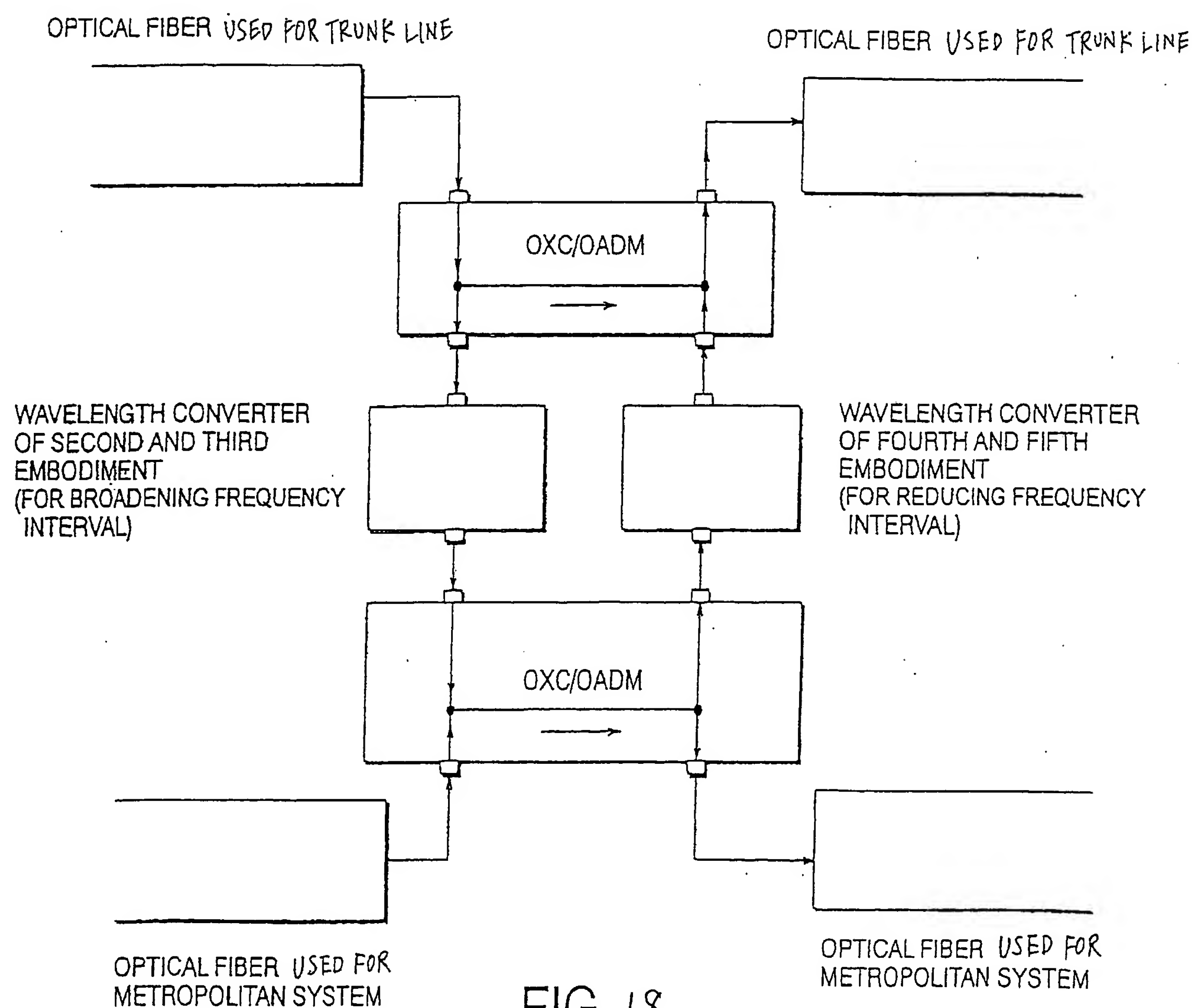

OPTICAL FIBER USED FOR TRUNK LINE
OPTICAL FIBER USED FOR TRUNK LINE
OXC/OADM
WAVELENGTH CONVERTER OF SECOND AND THIRD EMBODIMENT (FOR BROADENING FREQUENCY INTERVAL)
WAVELENGTH CONVERTER OF FOURTH AND FIFTH EMBODIMENT (FOR REDUCING FREQUENCY INTERVAL)
OXC/OADM
OPTICAL FIBER USED FOR METROPOLITAN SYSTEM
OPTICAL FIBER USED FOR METROPOLITAN SYSTEM

FIG. 18